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TRANSACTIONS

OF THE

INSTITUTION

OF

CIVIL ENGINEERS.

VOLUME II.

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TRANSACTIONS.

I.—*Account of the Bridge over the Severn, near the Town of Tewkesbury, in the County of Gloucester, designed by* THOMAS TELFORD, *and erected under his superintendence. By* W. MACKENZIE, *M.Inst.C.E.*

THE Tewkesbury Severn bridge was one of the works of Telford which that distinguished man thought deserving of especial notice, from its being a work of considerable magnitude, and attended with no small degree of difficulty in the execution, and having, after several years experience, been found to answer its intended purpose *.

The rendering more perfect the interior communication of the country, having of late years engaged much of the public attention, it became obvious that there was wanted a more direct line of intercourse between the rich districts which occupy the vale of the Severn, adjacent to the town of Tewkesbury; and that the construction of a bridge over the river at this place, and of a commodious road in the direction of Ledbury, would open an important communication into South Wales.

Act of Parliament.

These considerations led to obtaining an act of parliament to construct a bridge and also roads of approach to it, and to levy tolls, upon the credit of which, money might be borrowed.

Telford consulted, Oct. 1823.

The trustees appointed by the act having procured a plan consisting of three cast iron arches, proceeded to carry the same into effect; but misunderstandings having taken place between the trustees and the

* See account of Tewkesbury Bridge, communicated Aug. 11, 1828, by Thomas Telford. Original Communications, Vol. I., No. 46.

architect, all the parties interested solicited Telford to examine into and report upon the case. This after much hesitation he agreed to do.

Report, Dec. 12, 1823.

Having conferred with the trustees, their solicitor, and the contractor, Mr. M'Intosh—and having along with them examined the operations of the bridge, the draft of the contract, and the working drawings, Telford made the following report.

"1st. With regard to the works now in progress—the masonry of the abutment on the Tewkesbury side as far as performed, seems executed in a very proper manner; and the Shropshire stone which has been provided, appears in general to be of sufficiently good quality; some few are objectionable, as being subject to decomposition, and as it requires unremitting attention to discover those which are defective, as well as to watch over the quality of the mortar, and the manner in which the masonry is constructed, and the construction of the pilings and platforms, which have been unavoidable, and in general to attend on the part of the trustees, to see that the materials and workmanship are in every respect perfect in their several sorts, and agreeable to the plans and specifications, I consider it my duty to recommend that an experienced and otherwise properly qualified person be employed to attend the bridge operations.

"2d. As upon excavating the foundations it has been discovered that instead of rock or firm ground, as was expected and provided for in the specification and plans, there has on the eastern or Tewkesbury side been found only sand and gravel, so little united as to require a substantial platform laid at two feet greater depth than shewn in the drawings or described in the specification; and that in order to render the work sufficiently secure, a row of sheet piling must still be driven along the front and returns of this abutment; and further, that on the western side the foundation at the level of the river bed, and for ten feet under that level, consists of a clean fine sand, requiring to be either wholly excavated to get at firm ground, or the whole space for the abutment to be secured by long piles with a substantial platform formed by good sheet piling, all constructed in the most perfect manner. And this being the case with the two abutments, there is every reason to expect that the two piers in the river will require similar precautions.

"Now as all these operations are unprovided for in the specification and plans, and will unavoidably amount to a very serious expense, it is of the utmost importance that the trustees should be made acquainted with the amount

as nearly as can be ascertained. I have therefore required of the contractor to state the amount of what has been already incurred, and also to furnish an estimate of what those foundations, which are beyond what is comprehended by his proposal, will probably cost.

"The following is his statement:

	£	s.	d.
Platform and sheet piling to foundation of eastern abutment, including 2 feet of extra depth of masonry, and using Shropshire stone facing	352	2	6½
Foundation of western abutment, including long piling, sheet piling, platform complete, including pumping, &c. .	805	13	5
Two river pier foundations, supposed to cost	1800	0	0
	£2957	15	11½

"3d. Upon comparing the specification andfigured drawings with the draft of the contract, and these with what is required by some of the clauses in the act of parliament, it appears that sundry small differences exist which the trustees are bound to guard against; for instance, the act provides that the two river piers taken together shall not in any place above the line of low water be more than eighteen feet, whereas upon the working drawing at that level twenty feet are marked. I must therefore recommend that the plans and specifications be revised, and made to accord with the clauses of the act.

"4th. As Aberthaw lime has, from long experience, been proved by much the fittest for all masonry exposed to water, I recommend that the contractor be restricted to the use of it fresh from the kiln, mixed hot, and particularly well mixed and beat.

"Any small saving which would be made by using any other sort is ill acquired at the expense of certain excellence.

"5th. When once the plans, specifications, and contracts have been carefully revised and finally settled, no deviation therefrom of any consequence should be admissible, unless authorized in writing under the hand of the principal engineer or architect employed by the trustees and sanctioned by them; and where practicable the amount of the expense should be previously ascertained, and agreed to in writing by the contractor.

"6th. Some further explanation appears necessary with regard to the fencing of the roads and embankments, also with regard to the field-gates, with the roads into the fields, and culverts under them.

"7th. Some provision should be made for sinking pannels and grooves in the masonry, to receive the iron work perhaps under the direction and at the expense of the iron contractor.

"8th. There should be a very distinct understanding as to where the earth for embankments, &c., is to be procured, how the ground is to be left, and who is to pay for land and damages. It should, if possible, be left in a state to be drained: the embankments should be protected both along the tops and bottoms."

Telford appointed engineer.

This report having been made, and fresh difficulties having arisen in the progress of the work, Telford was, early in February, 1824, requested to revise all the contracts, and to recommend what plan should be adopted; and on the 3d of March he made the following report.

Telford's Report, March 3d, 1824.

"Having taken a section of the river Severn at the intended site of the bridge, when the water had risen to about 2 feet 8 inches of the top of the bank on the western side of the river, and having also proved the nature of the river bed by boring, and measured and compared the relative breadths of different parts of the channel; and having duly considered the nature of the navigation which is carried on, and the great and frequent floods to which the said river is subject, I am of opinion, under all the circumstances of the case, that it is most advisable to have one arch of cast iron, which shall span across the whole breadth of the channel, and of course leave the whole of the water (while the river is within its banks) quite unobstructed. I consider that an arch of 170 feet span is sufficient for this purpose, and that it may be constructed of proper stability without raising the roadway higher than has already been proposed. For the flood water when risen above the surface of the meadows, I propose providing, as always intended, 160 feet of opening, measured on the horizontal line, besides two culverts of 3 feet diameter each, and this I consider a sufficient water-way for the purposes of the country, as required by act of parliament.

"The distribution of this flood water-way I propose to be by having six small openings upon each abutment, and nine arches, of 12 feet span each, placed at three different places on the western side of the river, where a discharge of water is most required.

"I am of opinion, that with a view to economy, without entrenching upon the proper and necessary accommodation of the intercourse, the bridge may be made 24 feet in width between the side railings, this being 4 feet more than an

iron bridge I have constructed upon the great Holyhead Road, which being found quite sufficient, the only reason I have not recommended this of the same width is, that being near a town, and subject to a toll upon foot passengers, it seems advisable to have a footpath on each side; these I propose to be 3½ feet each, which will leave a clear carriage way of 17 feet.

"In the several public roads lately made under my directions, none of the embankments have been more than 30 feet at the top, the protecting rails being set along the extreme edge, and the thorn quicksets planted at three feet without them. This width being found by experience to be as much as necessary, I recommend that those which will form the approaches to the bridge shall be made 30 feet instead of 45; this being still further necessary in order to keep the skirts of the slopes within the limit of 60 feet, as assigned by the act.

"I have made the outlines of a design which corresponds with what I have here recommended for the bridge and its abutments, the detailed dimensions and particulars of construction remain to be described by working drawings and a written specification, but they will be regulated by what I have found by experience to answer in four several instances, three of them upon navigable rivers and tideways.

"Upon this newly arranged plan and the before mentioned conditions, I have, along with the contractors, carefully gone through the calculations and comparisons with the former plans upon which their proposals were founded, and the result is—that although the quantity of iron required by the present plan is greater than by the former, yet, as Mr. Hazeldine has at his works some of the apparatus used in the three similar bridges he has constructed for me, and his works being adapted and his workmen accustomed to the management of all the parts, he will execute this proposed plan of one arch of 170 feet span for the same sum as his former proposal contained, that is to say £4500.

"On the works comprehended in Mr. M'Intosh's contract for the former plan a small saving will be effected, thus—

Amount of proposal for former plan	£11400
Ditto of extra works in foundation, as per my Report, Dec. 12. .	2957
	14357
Estimated expense by the present plan	14052
Saving	£305

"Considering the present situation of the works, it will be necessary to extend the time for completion from May until the last day of July, 1825; but that all the masonry of the bridge necessary to receive the iron work shall be completed by the last day of October next.

"In the above mentioned estimates it is understood that the contractors are to give security for the due completion of the works, and maintaining them in a perfect state for the term of three years afterwards.

"Mr. M'Intosh is to pay damage for the land necessary for procuring earth for the embankments, but not for that upon which the embankments stand, or for any expense attending making gates or roads of accommodation to the adjacent fields.

"The modes of payment to be distinctly arranged, so as to be made at stated times upon the certificate of the resident engineer, countersigned by the principal engineer in the usual way.

"The trustees having now before them a full statement of my ideas as regards the nature of the plan best adapted to the situation, the mode of conducting the work, and the expense to be incurred, it remains with them to determine whether they will approve of the same; and if so to give me directions to prepare a perfect copy of the plan now signed by the parties, also proper working drawings and specifications, and an outline for contracts upon the same; and also to authorize me to give directions to the contractors to take the necessary measures to proceed with the works agreeably to this newly arranged plan for an arch of 170 feet span, with its approaches and embankments."

Plan accepted.

The trustees approved of the design of one arch, and the contractors agreed to the above statement, and to execute proper contracts for the performance of the work as soon as the plans and specifications should be prepared and adopted; the work was proceeded in without further delay. With the preceding report Telford presented a sketch of the proposed bridge, and so great was the confidence entertained by all parties of his talents and integrity, that they were willing to proceed with the work, without any other agreement than the following, which is written on the drawing.

"This is the outline of a design intended to be completed, with proper dissected drawings and specifications, and which design is referred to in the report of the undersigned Thomas Telford, dated this 3d day of March 1824, and

which we have all subscribed our names to. Dated this 3d day of March 1824.

Thos. Telford, Engineer.
W. Hazeldine, Contractor for Iron Work.
Hugh M'Intosh, Contractor.
J. Prosser, Chairman, Wm. Phelps, Joseph Longmore, } Committee appointed by the Trustees.
Jas. Sutton Olive, Clerk to the Trustees.

SPECIFICATIONS.

Masonry and approaches.

"The bridge to be constructed near the Mythe Hill, at the place now marked out, and some part of the work begun. It is to consist of one opening for the river channel, where the faces of the abutments at the springing of the arch are to be 170 feet apart. This springing is to be at the level of 1 foot 6 inches below the Grindstone level, or 5 feet 6 inches below the former flood line. The foundations of the masonry of the main abutments are to be sunk to and laid at 21 feet below the said Grindstone level, or 19 feet 6 inches below the aforesaid springing. These abutments are to be 20 feet in thickness and 31 feet 6 inches in length, and these dimensions are to be carried up to the springing, with the addition of the projecting string course.

"The land pier on the Tewkesbury side to be taken down to receive the springing of the underground arch and the aforesaid string course. The land pier on the Bushley side to have its foundations sunk to and the masonry laid at the depth of 13 feet under the aforesaid Grindstone, or 11 feet 6 inches below the springing of the main arch; it is to be 10 feet in thickness, and both the land piers are to be 31 feet 6 inches in length, and carried of these dimensions up to the springing of the main arch, with the addition of the projecting string course. Between the main abutments and land piers arches are to be made, that on the Tewkesbury side to be 20, and that on the Bushley side 24 feet span, the arch stones two feet in depth, with proper spandril walls. From the level of the springing of the main arch the masonry is to be carried up 3 feet to the bottom of the open land arches;—this portion of the work will be 30 feet 6 inches in width across upon an average.

"In the main abutments the outside work of their faces and sides is to consist of ashlar work of Shropshire stone, not less than 2 feet 6 inches in

breadth on the bed, on an average, including headers. The arch stones of the underground arches to be of square masonry, the springing stones of the large arch are to be 6 feet in breadth from the front edge, along the sides and back to be 3 feet in breadth. All the rest of the masonry is to be built with the flat bedded lias lime-stone from Brockeridge Common, or from Breedon Hill, or other stone of equally good shape and quality. The whole of the masonry under the level of flood line to be laid in mortar of Aberthaw pebbles; above the flood line the mortar may be made from the Brockeridge lias lime-stone, the mortar for all work 2 feet 6 inches inwards from the outside to be two parts of unslaked lime to three of clean sharp sand; the backing or inside mortar to be composed of two parts of unslaked lime to four of clean sharp sand; the whole to be made with fresh burnt lime carefully slaked with as little water as possible, and well beat.

"From the top of the aforesaid springing course up to the level of the roadway, the structure is to consist of arches, piers, and pilasters, also the pedestals above the roadway to be all agreeable to the annexed drawing, (Plate II. Fig. 2,) the outside facings of which are to be made with the best Breedon Hill stone neatly dressed and squared. The ashlars of the before mentioned outside work to be 18 inches broad on the bed, on an average, excepting the plinth course for the railing, which is to be 15 inches only.

"The walls of the aforesaid land arches, and the arches themselves, and their spandrils, are to be of good sound hard burnt brick, laid in lime mortar and from the lias lime-stone of the country.

Platforms, Plate II. Fig. 6.

"Under the main abutment on the Tewkesbury side there is to be a platform consisting of two thicknesses of half baulk laid across, and pinned together with oak pins, to be 33 feet 6 inches in length and 22 feet in breadth, with a row of pile planking of elm or beech timber shod with iron, 10 feet long and 5 or 6 inches in thickness, secured to sills by $\frac{3}{4}$inch screw bolts; the sills to be fir or elm, 10 inches by 8, secured by strong iron rag bolts. The pile planking to be placed along the whole of the front, and for 8 feet returned along on each side.

Plate II. Figs. 1, 5.

"Under the whole space of foundation of the abutment, on the Bushley side, there are to be driven bearing piles 21 feet long and 12 or 13 inches square, placed at the distance of 3 feet from centre to centre, upon these transverse sills 12 inches by 6 inches are to be placed and spiked to the heads of the piles by rag bolts, and crossed by other

sills of similar dimensions spiked to the before mentioned, the spaces between the sills and pile heads to be filled with rubble stone rammed in and grouted with Aberthaw lime mortar; the whole of this grating to be covered with 6-inch planking pinned down with oaken pins, the whole of the piles, grating, and planking to be of good Baltic timber, the piles to be shod with iron. Sheeting piles of elm or beech 12 feet long and 6 inches thick to be driven along the whole of the front, and for 10 feet along each side. Under the foundation of the land abutment on the Bushley side, there is to be a grated platform consisting of two rows of sills and planking with round piles under them, as per annexed plan.

"The spandrils of the land arches are to be filled up either with brick work or flat bedded lias limestone to the level of the lower side of the roadway, but along the face of the abutments next the iron arch the whole outside stones are to be squared ashlars, not less than 2 feet broad on the bed on an average; the two top courses to be not less than 3 feet in breadth, and in both those facings grooves are to be cut to receive the springing plates and the plates for the lozenge standards and bearing bars.

"From the extremity of the wing walls of the bridge, rubble walls with a proper coping to be built with lime to prevent the embankment slopes from encroaching on the aforesaid wing walls of the bridge, in the manner and to the extent of the general plan and elevation signed by Thomas Telford, and to his satisfaction.

Roadway over the bridge and land arches.

"The whole of the iron plates over the main arch and the whole space over the land arches and piers to be covered with a coat of good clay properly punned so as to render it water tight; upon this, along each side of the bridge, a footpath, 3 feet 6 inches in breadth, is to be formed in the following manner; that is to say, to have a curb stone of squared granite 1 foot 6 inches in depth, and 9 inches in thickness, the space between the curbing and the iron work to be composed of suitable gravel.

"The carriage way between the curbings to be 17 feet in width, to be covered with stone for the whole width, the foundation or first course to consist of such hard materials as may be procured from the fields or limestone quarries in the neighbourhood, and to be 7 inches thick on the middle and 3 inches at the sides, and the upper coat of best Bristol limestone of an average thickness of 5 inches; the whole to be broken into pieces, none exceeding 6 ounces.

Flood Arches.

"There are to be nine flood arches, that is three sets of

three arches each, and each arch to be 12 feet span, they are to be placed where the discharge of water in the low ground on the western side is most required, the foundations to be sunk to such a depth that the inverts may suit the natural watercourses and the surface of the adjacent ground; the abutments are each to be 3 feet in thickness, with two counterforts behind each, each 4 feet by 3; the piers are each to be 1 foot 6 inches in thickness, and both abutments and piers to be 36 feet in length, the arches are to be 14 inches in thickness and 36 feet in length across the road. The inverted arches are each to be 9 inches in thickness with a curve of 12 inches. The spandril walls are to be 1 foot 10 inches in thickness, the wing walls are to be from 3 feet in thickness to 14 inches, and to have a coping of 4½ inches. At the springing of the arches there are to be courses of stone 18 inches broad by 12 inches thick. All the rest of the work is to consist of good, sound, hard burnt bricks laid in proper lime mortar. The sprandrils of the arches are to be made up with either brickwork or flat bedded lias limestone laid in lime mortar. Over the top of all the arches and spandrils there is to be laid six inches of clay well punned. Besides the aforesaid arches there are to be two culverts, 3 feet diameter, of a proper length to extend to the skirts of the embankment where they are placed.

Embanked Approaches.

"The approaches to each end of the bridge to be agreeable to the annexed plan and section signed by the said Thomas Telford. The longitudinal line of roadway in no case to rise more than 1 in 35. The width of the finished top to be 30 feet, and the side slopes to be 1½ horizontal to 1 perpendicular. The roadway to be made with stone 27 feet in width, constructed of the same thickness and manner as described for the carriage way over the main bridge.

"Each side of the road to be formed with sawed oak posts, and Baltic fir rail fences, three rails in height according to the drawing, the posts to be fixed 8 feet asunder, to be 8 feet 6 inches long, and 4 feet 6 inches above the ground, with proper spurs at the butt-end, equal to 1 foot diameter and 4 feet in the ground at least.

"The rails to be morticed and tennoned into the posts, to be rounded on the upper surface and secured by oak pins, the top rail to be 6 inches by 4 inches, the middle 5 inches by 4 inches, and the bottom 5 inches by 3½ inches; the posts and rails to be free from sap, and to be covered with paint, of three coats, of a light stone colour, of a quality prepared and generally used for that purpose.

" The road from the termination of the embankment to the intersection of the old Ledbury road, to be fenced on each side with cleft oak post and rail fencing, three rails between the posts, the posts to be fixed upon the quickset banks, which are to be raised of a sufficient height and breadth as may be necessary for the lands adjoining.

River Banks. " The river banks on each side of the eastern abutment to be embanked with earth so as to range with the front of the abutment, its face to have a slope of 2 horizontals to 1 perpendicular above low water mark, and all below low water mark to be secured with stakes and faggots. The face of the embankment to be covered with good turf fixed down with wooden pins. On the western side, above and below the abutments, the river bank to be dressed to range with the front of the abutment, the slope to be the same as described for the eastern side, and to be covered and secured in a similar manner.

Iron Work, Plate III. " The bridge is to be constructed over the river Severn, near the Mythe Hill, where the site is marked out and the work begun. The main opening for which this arch is to be adapted is to be one hundred and seventy feet between the abutments' springing plates, the springing is to be 1 foot 6 inches below the grindstone level, or 5 feet 6 inches below the former flood line, the rise or versed sine is to be 17 feet, and the width to be such as to leave 24 feet clear between the skirting of the roadway railing; there are to be six ribs placed at equal distances from each other, they are to be placed upon strong abutment-plates, firmly bedded in the masonry; they are to be secured in their places by gauge pipes and connecting wrought iron bolts, covered with grated plates fixed by mortices fitted to joggles in the main ribs, and screwed flanches; upon these the lozenge spandril standards are placed, which are also secured by gauge pipes and cross ties in the middle, and by mortices and tenons at top and bottom, besides diagonal braces in the spandrils. Upon the top of these the road bearers are to be fixed one over each rib, upon these bearers the road plates are to be laid joggled upon the bearers and screwed together by their own flanches and pins; upon these road plates the iron skirting is to be placed, to protect the road and receive the common railing; the main rails are to be placed and screwed upon the road plates, the railing is to be capped with a hand rail. The whole of the cast iron work to be of the best Shropshire iron, No. 2, cast, fitted, and put up complete, in the most perfect manner.

"The contractor is to provide all materials, tools, utensils, machinery, scaffolding,

and labour of all sorts which may be required for making, carrying, fitting up, and completing the said arch, spandrils, roadway, and railing agreeably to the before mentioned drawings, and the general plan and elevation of the bridge made out and signed by Thomas Telford, where it will be observed the cast iron railing is carried not only along the great iron arch, but also over the six land arches on each side, and that the columns between the small arches in the bridge wings are to be made of cast iron."

REFERENCES TO PLATES.

PLATE I.

General plan and elevation of the bridge.

PLATE II.

Fig. 1. Elevation of abutment, with the piles on the Bushley side.

Fig. 2. Elevation of abutment on the Tewkesbury side, with the open land arches.

Fig. 3. Plan of ditto.

Fig. 4. Cross section through the Bushley side abutment, and first land arch.

Fig. 5. Plan of platform for the main abutment on the Bushley side.

Fig. 6. Plan of platform for the main abutment on the Tewkesbury side.

PLATE III.

Fig. 1. Elevation of a main rib, lozenges, skirting and railing.

Fig. 2. Plate for connecting main ribs.

Fig. 3. Shews the manner in which the several pieces of the main ribs are connected together. The flanges of the ribs are 4 inches deep. In the four middle ribs, where there are double flanges, there are three $1\frac{1}{2}$ inch bolts in each flange; but in the two outside ribs, where there is only a single flange, it has four of these bolts.

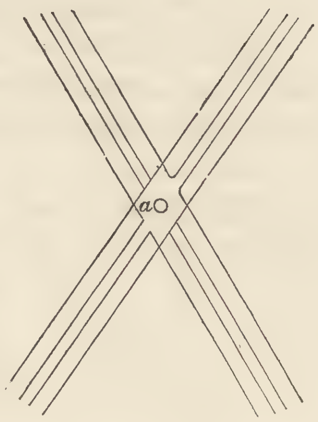


Fig. 4. Section of one of the lozenges of the spandrils taken at the middle of the length. They diminish to $3\frac{1}{2}$ inches square at the ends; they are joined at the middle by a mortice and tenon (as in accompanying sketch); they are connected breadthways of the bridge by wrought iron bolts, $1\frac{1}{2}$ inch diameter, passed quite across through holes in the middle of the crosses, (as at *a*, in the figure,) and also through cast iron tubes, placed between each row of lozenges, to prevent their being drawn out of their places when the bolts are screwed up. These tubes are represented in the following figure. External diameter $2\frac{1}{2}$ inches. Internal diameter $1\frac{1}{2}$ inch.

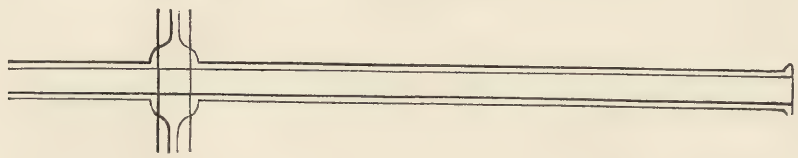


Fig. 5. Main ballusters.

Fig. 6. Section of handrail.

Fig. 7. Skirting.

Fig. 8. Road plates $\frac{7}{8}$ inch thick; flanges 3 inches high inside; dovetailed joggles to fasten the plates to the road-bearers, 6 inches long, $1\frac{1}{4}$ thick, and $1\frac{1}{2}$ high; $\frac{7}{8}$ screw-pins.

Fig. 9. Section of diagonal braces; in the middle they are $5\frac{1}{2}$ inches square, at the ends only 4 inches. Instead of being joined together where the two parts of the cross meet by a mortice and tenon, they are simply halved into each other, and a bolt holds the two together. There are two pair of these braces on each side of the crown of the arch; they meet at the joining of the second and third rib plates, from the crown of the arch on each side.

Fig. 10. Shews the manner in which the road-bearers are connected with the abutments; the road-bearers are cast in four lengths on each side of the crown of the arch, and are joined to each other with two $1\frac{1}{8}$ inch bolts, as in annexed figure.

Fig. 11. Springing plate.

Fig. 12. Plates for connecting and covering the top of the main ribs; nine 1 inch screw bolts connect every two of these plates. Flanges stand up 3 inches inside. The joggles, which are cast upon the top of the main ribs, and upon which these plates are let down, have each a mortice in the top to receive the tenons of the lozenges or crosses of the spandrils.

Fig. 13. Capital and base of the cast iron columns.

Fig. 14. Shews the proportional lengths of the cast iron columns.

II.—*A Series of Experiments on different kinds of American Timber.* By W. Denison, *Lieut. Royal Engineers, F.R.S., A.Inst.C.E.*

The following Tables contain the results of experiments on different kinds of American timber; they are not so complete as I could wish, such, however, as they are, I submit them to the Institution. Some of them corroborate in a remarkable degree the experiments made by Mr. Barlow upon wood of the same nature, but of very different scantling, and under different circumstances. My object in commencing these experiments was twofold; I wished, in the first place, to establish some proportion between the strength of different kinds of American timber, and then, by reference to Mr. Barlow's experiments, between these and European timber; so as to enable me to supply the place of the constant factors which enter into the rules or formulæ by which the dimensions of timber for different purposes may be calculated with some degree of correctness; and, in the second place, to ascertain the difference, both in dimension and strength, made by seasoning, or by difference of age, or position in the tree. For this purpose I had trees felled as nearly as possible of the same size; from these I sawed a plank through the heart of the block, and this plank was afterwards divided into pieces for experiment one inch square and three or four feet in length, which were numbered according to their position in the tree from the sap inwards.

I commenced experimenting at once upon some of these specimens in their green state, intending to reserve the others until they were seasoned, having noted upon each its dimensions when green, for the purpose of ascertaining the amount of shrinkage in seasoning. My return to England, which was unexpected, unluckily put a stop, not only to these experiments, but also to some on a much larger scale for which I had the timber already prepared. Having said thus much in explanation of the motives which induced me to make these experiments, I shall proceed shortly to describe the apparatus I employed, in order that the Institution may judge of the degree of confidence to be placed in the results.

Description of the apparatus employed. Plate IV. Figs. 1, 2, 3.

Two blocks of oak, about 6 inches square and 4 feet high, were morticed firmly into a 3 inch plank, and further supported by struts, as shewn in the drawing. They were tied together at the top by a cross bar, which by the way in which it was notched into the uprights acted

both as a tie and a strut; this cross bar served at the same time to support a graduated circle which indicated the amount of deflection: (the radius of the divided circle being ten times that of the barrel which communicated motion to the index, as ascertained by frequent comparisons, the smallest deflection was easily measured.) A groove was cut in the top of each of the uprights to receive the specimens; it was lined with iron, as shewn in the sketch, and in order that it might be possible, if wished, to fix the ends of the timber subjected to experiment, two screws were riveted to this lining, and a cap constructed which might be screwed fast on the specimen.

The specimen being carefully measured, was placed upon the supports; the first weight it had to sustain was that of the scale and ropes, and weights to make up 20 lbs.*; the deflection was then noted, and after that weights added by 20 lbs. at a time, noting carefully the deflection after each addition. When it was thought likely that the limit of elasticity was nearly attained, the weights were added more gradually and allowed to remain longer, the changes of deflection were closely watched, and the weights often removed to ascertain whether or no the specimen would return to its original state. After the limit of elasticity was once passed, the weights were added quickly till the specimen gave way; the flexure at the time of fracture was noted as near as possible, but upon this, of course, much reliance cannot be placed. As soon as the experiment was concluded, a piece of the specimen was cut off and the specific gravity determined.

I cannot conclude without expressing my hopes that officers and others employed in the colonies will be induced to turn their attention to this subject. In America especially, for many years, timber from its cheapness will be employed in preference to iron, and should Mr. Kyan succeed in his attempts to secure it from the attacks of insects, and from natural decay, we may look forward in that country, at all events, to its employment in a variety of situations where its destructibility is now a complete bar to its use.

* This applies to the later experiments; at first I was obliged to make use of the weights I could procure on the spot, but I afterwards had others cast on purpose.

Experiments on the STRENGTH of TIMBER when exposed to a Transverse Strain, carried on in Canada in the Years 1830 and 1831, and the Results of the Experiments calculated according to Formulæ given by Barlow.

No. of Experiment.	Names of Woods.	Length in inches $=l$.	Breadth $=a$.	Depth $=d$.	Specific gravity.	Weight applied.	Deflection in inches $=\Delta d$.	Remarks.	Value of S from formula $S=\frac{lW}{4ad^2}$.	Value of S′ from formula $S'=\frac{lW\sec^2\Delta}{4ad^2}$.	Columns of Differences. Weights.	Columns of Differences. Deflection.
1	Canadian	24	·99	·99	786·4	71	·1	Ends loose on supports.				
	White Oak,					127	·2				56	·1
	seasoned.					155	·26	In 5′=·28, weight taken off. Set=0			28	·06
						183	·38	In 10′=·40			28	·12
						211	·50	In 10′=·56, weight taken off. Set=·05			28	·12
						239	·73	In 5′=·76	1824	1902	28	·23
						253	·85				14	·12
						267	1·01				14	·16
						281	1·15	In 30′=1·73, weight taken off. Set=·53			14	·14
						288	1·80	In 10′=1·90, began to crack.			7	·65
						295		Broke in 5′, deflection=2·43			7	Broke
2	Do. seasoned.	24	·975	·97	763·6	71	·15	Ends loose in support.				
						99	·21				28	·06
						127	·27				..	·06
						155	·33	Weight taken off. Set=0			..	·06
						183	·40	In 20′=·45, weight taken off. Set=·05			..	·07
						211	·52				..	·12
						239	·60	In 10′=·62			..	·08
						253	·67	In 20′=·70			14	·07
						267	·75				..	·08
						281	·80		2388	2456	..	·05
						295	·85				..	·08
						309	·93				..	·07
						323	1·00	In 10′=1·05			7	·1
						330	1·10				..	·05
						337	1·15	All weights taken off. Set=·3			..	·1
						344	1·25				..	·15
						351	1·40				..	·1
						358	1·50	Began to crack, and broke in about 10 minutes,			..	·05
						365	1·55	deflection at instant of fracture 1·85				
3	Do. White	24	1·01	1·0	918	20	·04					
	Oak, green.					40	·09				20	·05
						60	·14				..	·05
						80	·19				..	·05
						100	·25				..	·06
						120	·31	Weight taken off. No set.			..	·06
						140	·37		1544	1576	..	·06
						160	·45	Set = ·03			..	·08
						180	·57	In 5′= ·60			..	·12
						200	·70	In 5′= ·75			..	·13
						220	·85	In 10′= ·95			..	·15
						240	1·05	In 5′=1·15			..	·2
						260	1·40	Broke, deflection at instant of fracture = 1·75			..	.35
4	Do. green.	24	·985	1·0	1034	20	·04	Heart of tree.				
						40	·10	A faulty specimen, though cut from the same			20	·06
						60	·16	block as the former, the upper surface was			..	·06
						80	·22	weakened by a knot.			..	·06
						100	·28				..	·06
						120	·37	Weights taken off. Set=·02	1340	1370	..	·09
						140	·48				..	·11
						160	·59	In 5′=·63			..	·11
						180	·83				..	·24
						200	·98	In 5′=1·08			..	·15
						220	1·25	Broke, deflection at instant=1·83			..	·27
5	Do. heart of	24	1·0	1·0	951	20	·05	This and the two following specimens were				
	tree.					40	·10	cut from the same tree.			20	·05
						60	·15		1500	1652	..	·05
						80	·20				..	·05
						100	·25				..	·05
						120	·30	No set.			..	·05

EXPERIMENTS CONTINUED.

No. of Experiment.	Names of Woods.	Length in inches $= l$.	Breadth $= a$.	Depth $= d$.	Specific gravity.	Weight applied.	Deflection in inches $= \Delta d$.	Remarks.	Value of S from formula $S = \frac{l W}{4 a d^2}$.	Value of S′ from formula $S' = \frac{l W \sec^2 \Delta}{4 a d^2}$.	Columns of Differences.	
											Weights.	Deflection.
5	Canadian White Oak, heart of tree.	24	1·0	1·0	951	140	·40					
						160	·50	In 3′ = ·55			20	·1
						180	·65	.. = ·72			..	·1
						200	·82	.. = ·95			..	·15
						220	1·10	.. = 1·40	1500	1652	..	·17
						240	1·60	In 5′ = 2·45			..	·28
						250	3·83	Broke gradually, being equally strained			..	·5
								throughout.			..	·23
6		24	1·01	1·0	939	20	·06					
						40	·12				20	·06
						60	·18				..	·06
						80	·25				..	·07
						100	·33	Set hardly perceptible.			..	·08
						120	·45		1188		..	·12
						140	·55	Set = ·05			..	·1
						160	·65	In 3′ = ·72			..	·1
						180	·83	.. = ·94			..	·18
						200	1·05	Gave way at a knot 5 inches from the centre.			..	·22
7	Do.	24	1·02	1·0	798	20	·04					
						40	·08				20	·04
						60	·12				..	·04
						80	·16				..	·04
						100	·21				..	·05
						120	·27	No set.			..	·06
						140	·33				..	·06
						160	·40	In 3′ = ·44 Set = ·02	1764	1854	..	·07
						180	·51	.. = ·55			..	·11
						200	·62	.. = ·68			..	·06
						220	·75	.. = ·82			..	·13
						240	·89	.. = 1·02			..	·14
						260	1·09	.. = 1·32			..	·2
						280	1·62	.. = 1·80			..	·53
						300	1·92	Broke gradually, deflection = 2·72			..	·3
8	White Oak.	24	1·0	1·0	788·9	20	·05	These specimens were pretty dry.				
						40	·10				20	·05
						60	·15				..	·05
						80	·20				..	·05
						100	·25				..	·05
						120	·30				..	·05
						140	·35				..	·05
						160	·42	Set = ·05	1680	1700	..	·07
						180	·49				..	·07
						200	·58	In 3′ = ·62			..	·09
						220	·72				..	·14
						240	·82	In 3′ = ·92			..	·1
						260	1·13	Broke suddenly. I had not time to observe			..	·31
						280	1·32	the ultimate deflection.			..	·19
9	Do.	24	1.01	1·01	789·6	20	·047	In this and the former specimen the wood was				
						40	·095	cut in some measure across the grain, and			20	·048
						60	·142	they both broke with a long splinter in the			..	·047
						80	·189	direction of the fibres. They cannot, there-			..	·047
						100	·236	fore, give a fair estimate of the absolute			..	·047
						120	·283	strength.			..	·047
						140	·33	In 2′ = ·34	1630	1654	..	·047
						160	·39	.. = ·40 Set = ·05			..	·06
						180	·47	.. = ·49			..	·08
						200	·57	.. = ·66			..	·1
						220	·68	.. = ·75			..	·11
						240	·82	.. = ·93			..	·14
						260	1·02	.. = 1·20			..	·2
						280	1·35	.. = 1·50 Broke suddenly.			..	·33

EXPERIMENTS CONTINUED.

No. of Experiment.	Names of Woods.	Length in inches $= l$.	Breadth $= a$.	Depth $= d$.	Specific gravity.	Weight applied.	Deflection in inches $= \Delta d$.	Remarks.	Value of S from formula $S = \frac{l\,W}{4\,a\,d^2}$.	Value of S′ from formula $S' = \frac{l\,W \sec^2 \Delta}{4\,a\,d^2}$.	Columns of Differences. Weights.	Columns of Differences. Deflection.
10	White Oak.	24	1·0	1·0	790	20	·045					
						40	·09				20	·045
						60	·135				..	·045
						80	·18				..	·045
						100	·225				..	·045
						120	·27				..	·045
						140	·33				..	·06
						160	·39	Set = ·04			..	·06
						180	·44	In 2′ = ·46	2040	2111	..	·05
						200	·52	.. = ·535			..	·08
						220	·59	.. = ·63			..	·07
						240	·685	.. = ·745			..	·095
						260	·80	.. = ·87			..	·115
						280	·89	.. = 1·01			..	·09
						300	1·08	.. = 1·37			..	·19
						320	1·46	.. = 1·80			..	·38
						340		Broke, deflection at instant = 2·25			..	Broke
11	Do.	24	·99	·98	760·4	20	·045					
						40	·095				20	·05
						60	·15				..	·055
						80	·205				..	·055
						100	·255				..	·05
						120	·32	Set = ·03	1514	1527	..	·065
						140	·375	In 2′ = ·41			..	·055
						160	·465	.. = ·51			..	·09
						180	·565	.. = ·625			..	·1
						200	·685	.. = ·785			..	·12
						220	·855	.. = ·955			..	·17
						240	·925	.. = 1·12 Broke suddenly.			..	·07
12	Do. pretty dry.	24	·98	·98	738·5	20	·055					
						40	·11				20	·055
						60	·165				..	·055
						80	·22				..	·055
						100	·275				..	·055
						120	·35	Set = ·02	1530	1551	..	·075
						140	·41	In 2′ = ·455			..	·06
						160	·51	.. = ·575			..	·10
						180	·64	.. = ·710			..	·13
						200	·78	.. = ·800			..	·14
						220	·95	.. = 1·15			..	·17
						240	1·25	Broke, deflection = 1·43			..	·3
13	Do.	24	·98	·98	736	20	·06					
						40	·10				20	·04
						60	·15				..	·05
						80	·19				..	·04
						100	·23				..	·04
						120	·28				..	·05
						140	·33	Set = ·02			..	·05
						160	·38	In 2′ = ·41	1912	1962	..	·05
						180	·46	.. = ·49			..	·08
						200	·55	.. = ·60			..	·09
						220	·67	.. = ·72 Set = ·14			..	·12
						240	·79	.. = ·91			..	·12
						260	·98	.. = 1·13			..	·19
						280	1·24				..	·26
						300	1·94	Broke.			..	·7
14	Rock Elm, seasoned	24	·985	1·005	748·7	71	.13					
						99	.17				28	·04
						127	.22	Same in 10′			..	·05
						155	.27	In 10 = ·28, weights taken off set = ·0	2623·4	2666.8	..	·05
						183	.32	No set.			..	·05
						211	.37	No set.			..	·05
						239	.45	No set.			..	·08

EXPERIMENTS CONTINUED.

No. of Experiment.	Names of Woods.	Length in inches $=l$.	Breadth $=a$.	Depth $=d$.	Specific gravity.	Weight applied.	Deflection in inches $=\Delta\ d$.	Remarks.	Value of S′ from formula $S=\frac{l\,W}{4\,a\,d^2}$.	Value of S from formula $S'=\frac{l\,W\sec^2\Delta}{4\,a\,d^2}$.	Columns of Differences. Weights.	Columns of Differences. Deflection.
14	Rock Elm, seasoned.	24	·985	1·005	748·7	267	·51	In half an hour = ·55. Set = ·03			..	·06
						281	·60				14	·09
						295	·64				..	·04
						302	·67	In 10′ = ·68			7	·03
						309	·70	In 6′ = ·71			..	·03
						316	·75				..	·05
						323	·78				..	·03
						330	·80				..	·02
						337	·82				...	·02
						344	·84				..	·02
						349	·88				5	·04
						351	·92	All weights taken off. Permanent set = ·1	2623·4	2666·8	..	·04
						358	·96				7	·04
						365	1·01				..	·05
						372	1·06				..	·05
						379	1·1				..	·04
						386	1·15				..	·05
						393	1·2				..	·05
						400	1·25				..	·05
						407	1·32					·07
						414	1·40					·08
						421	1·47					·07
						428	1·55					·08
						435	1·85	In 20 minutes began to give, and broke soon after; deflection at the instant of fracture = 2·1				·3
15	Do.	24	·985	·99	754	71	·07					
						99	·13				28	·06
						127	·19				..	·06
						155	·25	No set. } The weights fell from my hand; caused the great deflection.			..	·06
						183	·37				..	·12
						211	·45	In 30′ = ·57. Set = ·1			..	·08
						239	·70		2000	2112·8	..	·25
						267	·90				..	·2
						281	1·15				14	·25
						295	1·30	In 20′ = 1·67			..	·15
						309	1·83				..	·53
						323	1·90	Began to crack and broke soon, deflection at instant 2·85.			..	·07
16	Do. Green.	24	·985	1·0	740·6	20	·03					
						40	·09				20	·06
						60	·15				..	·06
						80	·21				..	·06
						100	·27				..	·06
						120	·33	No set.			..	·06
						140	·40	In 5′ = ·42 Set = ·04			..	·07
						160	·52	.. = ·55	1705	1750	..	·12
						180	·65				..	·13
						200	·77	.. = ·80			..	·12
						220	·90	.. = ·95			..	·13
						240	1·10	.. = 1·20			..	·2
						260	1·40	.. = 1·50			..	·3
						280	1·65	Broke, deflection = 1·95			..	·25
17	Do. Green.	24	·985	1·02	745·5	20	·05	Both this specimen and the former were very straight in the grain and free of knots, and were fairly strained.				
						40	·10				20	·05
						60	·15				..	·05
						80	·20				..	·05
						100	·26				..	·06
						120	·33	No set.	1705	1764	..	·07
						140	·40				..	·07
						160	·50	Set = ·53			..	·1
						180	·63	.. = ·65			..	·13
						200	·75	.. = ·80			..	·12
						220	·90	.. = ·95			..	·15

EXPERIMENTS CONTINUED.

No. of Experiment.	Names of Woods.	Length in inches $= l$.	Breadth $= a$.	Depth $= d$.	Specific gravity.	Weight applied.	Deflection in inches $= \Delta d$.	Remarks.	Value of S from formula $S = \frac{lW}{4ad^2}$.	Value of S′ from formula $S' = \frac{lW \sec^2 \Delta}{4ad^2}$.	Columns of Differences. Weights.	Columns of Differences. Deflection.
17	Rock Elm, Green.	24	·985	1·02	745·5	240	1·10	Set = 1·20	1705	1764		
						260	1·50	.. = 1·60			20	·4
						280		Broke, deflection 2·25				
18	Weeping Ash, Green.	24	1·01	1·0	761·5	20	·06					
						40	·12				20	·06
						60	·18				..	·06
						80	·24				..	·06
						100	·32				..	·08
						120	·40				..	·08
						140	·55	Set = ·05			..	·15
						160	·75				..	·2
						180	1·05				..	·3
						200	1·80				..	·75
						210	2·70				10	·9
						220	7·3	Slipped through supports without breaking, and had then a set of 1·0 inch.			..	4·6
19	Do.	24	1·0	1·04	763	20	·03	This specimen exhibited but a very slight symptom of fracture after slipping through the support, it had a set of 1·3 and an hour afterwards this was reduced 1·0.				
						40	·06				20	·03
						60	·09				..	·03
						80	·15				..	·06
						100	·21				..	·06
						120	·28	No set.			..	·07
						140	·40				..	·12
						160	·52				..	·12
						180	·67				..	·15
						200	·95				..	·28
						220	1·45				..	·5
						240	2·05	In 5′ = 3·0			..	·60
						250	3·90	In 10′ = 5·8			10	1·85
						260	7·0	Slipped through supports.			..	3·1
20	White Ash, Green.	24	1·03	1·04	781	20	·03					
						40	·063				20	·033
						60	·097				..	·034
						80	·131				..	·034
						100	·164				..	·033
						20	·198				..	·034
						40	·232				..	·034
						60	·265				..	·033
						80	·299		1938	1989	..	·034
						200	·332				..	·033
						20	·38				..	·048
						40	·43	In 5′ = ·45 Set = ·04			..	·05
						60	·53				..	·1
						80	·63				..	·1
						300	·73	.. = ·77			..	·1
						20	·85	.. = ·90			..	·12
						40	1·05	.. = 1·2			..	·2
						60	1·4	Broke, deflection = 1·95			..	·35
21	Do.	24	1·02	1·04	698	20	·02					
						40	·054				20	·034
						60	·088				..	·034
						80	·122				..	·034
						100	·156				..	·034
						20	·190				..	·034
						40	·224				..	·034
						60	·258		1958	2009	..	·034
						80	·292				..	·034
						200	·340	No set.			..	·034
						20	·40				..	·048
						40	·47				..	·06
						60	·57	Set = ·60			..	·07
						80	·67	.. = ·70			..	·1
						300	·80	.. = ·85			..	·1

EXPERIMENTS CONTINUED.

No. of Experiment.	Names of Woods.	Length in inches $= l$.	Breadth $= a$.	Depth $= d$.	Specific gravity.	Weight applied.	Deflection in inches $= \Delta d$.	REMARKS.	Value of S from formula $S = \frac{l\,W}{4ad^2}$.	Value of S′ from formula $S' = \frac{l\,W \sec^2 \Delta}{4\,a\,d^2}$.	Columns of Differences. Weights.	Columns of Differences. Deflection.
21	White Ash, Green.	24	1·02	1·04	698	320	1·0	Set = 1·05	1958	2009	20	·13
						40	1·35	.. = 1·40			..	·2
						60		Broke; deflection = 1·95			..	·35
22	White Ash, seasoned partly.	24	·96	·98	641·6	20	·045				20	·05
						40	·095				..	·035
						60	·13				..	·045
						80	·175				..	·045
						100	·22				..	·04
						20	·26				..	·05
						40	·305				..	·05
						60	·355	Set = ·015	2082	2126	..	·05
						80	·405				..	·065
						200	·47	Set = ·50			..	·08
						20	·55	.. = ·57			..	·08
						40	·63	.. = ·68			..	·1
						60	·73	.. = ·79			..	·13
						80	·86	.. = ·94			..	·27
						300	1·03	.. = 1·15			..	·21
						320	1·24	Broke, 1·75 with a long splinter.				
23	Do.	24	·96	1·0	643	20	·047				20	·048
						40	·095				..	·05
						60	·145				..	·045
						80	·19				..	·035
						100	·225				..	·045
						20	·27				..	·05
						40	·32				..	·04
						60	·36	Set = ·02	2000	2040	..	·06
						80	·42				..	·06
						200	·48				..	·07
						20	·55	Set = ·61			..	·11
						40	·66	.. = ·74			..	·13
						60	·79	.. = ·88			..	·17
						80	·96	.. = 1·09			..	·21
						300	1·17	.. = 1·45			..	·38
						320	1·55	Broke fairly, deflection = 1·70				
24	Rock Elm, Green.	24	·93	·97	743	20	·05				20	·06
						40	·11				..	·05
						60	·16				..	·04
						80	·20				...	·05
						100	·25				..	·04
						20	·29				..	·05
						40	·34				..	·05
						60	·39	Set = ·02	2331	2380	..	·06
						80	·45				..	·06
						200	·51	= ·53 } in 2′			..	·07
						20	·58	= ·61			..	·08
						40	·66	= ·71			..	·1
						60	·76	= ·83			..	·14
						80	·90	= ·98			..	·14
						300	1·04	= 1·19			..	·22
						20	1·26	= 1·49			..	·32
						340	1·58	Broke with a long splinter, deflection = 1·75				
25	Do.	24	·97	·98	755	20	·04				20	·05
						40	·09				..	·05
						60	·14				..	·04
						80	·18				..	·04
						100	·22		2318	2399	..	·04
						20	·26				..	·04
						40	·30				..	·05
						60	·35	Set = ·03			..	·06
						80	·41				..	·06
						200	·47	= ·49 } in 2′			..	·07
						20	·54	= ·57				

EXPERIMENTS CONTINUED.

No. of Experiment.	Names of Woods.	Length in inches = l.	Breadth = a.	Depth = d.	Specific gravity.	Weight applied.	Deflection in inches = Δ d.	REMARKS.	Value of S from formula $S = \frac{l\,W}{4\,a\,d^2}$.	Value of S' from formula $S' = \frac{l\,W\,\sec^2\Delta}{4\,a\,d^2}$.	Columns of Differences. Weights.	Deflection.
25	Rock Elm, Green.	24	·97	·98	755	240	·62	= ·67			20	·08
						60	·72	= ·80			..	·1
						80	·86	= ·91 } in 2'			..	·14
						300	·97	=1·09	2318	2399	..	·11
						20	1·16	=1·30			..	·19
						40	1·37	=1·62			..	·21
						360	1·75	=2·20 cracked.			..	·38
26	Swamp Ash, Green.	24	·96	·98	931·7	20	·06					
						40	·13				20	·07
						60	·20				..	·07
						80	·27		1141		..	·07
						100	·43				..	·16
						40	1·00	In 5'=1·18			40	·57
						160		Broke, deflection = 1·68			..	Broke
27	Do.	24	1·0	·98	919·6	20	·03					
						40	·09				20	·06
						60	·15				..	·06
						80	·21				..	·06
						100	·30				..	·09
						20	·51		1189		..	·21
						40	·63				..	·12
						60	1·03				..	·4
						70	1·30				10	·27
						80	2·00				..	·7
						190		Broke, deflection = 2·33			..	Broke
28	Black Ash, green.	24	·98	1·0	608	71	·40					
						99	·97				28	·57
						113	1.40	In 5'=1·50	735		14	·43
						120		Gave way suddenly.			7	Broke
29	Do.	24	·98	·98	·458	71	·28					
						127	·75		988		56	·47
						155		Broke in 3 minutes.			28	Broke
30	White Hickory. Specimen pretty dry.	24	·97	·97	839	20	·047					
						40	·095				20	·048
						60	·142				..	·047
						80	·189				..	·047
						100	·236				..	·047
						20	·28				..	·044
						40	·33	In 3' = ·35 Set = ·04			..	·05
						60	·39	.. = ·41			..	·06
						80	·46	.. = ·46			..	·07
						200	·54	.. = ·58			..	·08
						20	·66	.. = ·69			..	·12
						40	·76	.. = ·83	2170		..	·1
						60	·92	.. =1·00			..	·16
						80	1·10	.. =1·32			..	·18
						90	1·40	.. =1·53			10	·3
						300	1·62	.. =1·73			..	·22
						10	1·79	.. =1·90			..	·17
						330		The specimen cracked, and I released the Index, 330, however, made no fracture, and it would probably have stood a good deal more as the next specimen bent 4·6 before it gave a symptom of fracture.			..	
31	White Hickory. Pretty dry.	24	·94	·94	834	20	·05					
						40	·10				20	·05
						60	·16				..	·06
						80	·21		2240	2569	..	·05
						100	·26				..	·05
						20	·32				..	·06
						40	·40				..	·08

EXPERIMENTS CONTINUED.

No. of Experiment.	Names of Woods.	Length in inches $=l$.	Breadth $=a$.	Depth $=d$.	Specific gravity.	Weight applied.	Deflection in inches $=\Delta d$.	Remarks.	Value of S from formula $S=\frac{lW}{4ad^2}$.	Value of S′ from formula $S'=\frac{lW\sec^2\Delta}{4ad^2}$.	Columns of Differences. Weights.	Columns of Differences. Deflection.
31	White Hickory. Pretty dry.	24	·94	·94	834	160	·48				..	·08
						80	·55				..	·07
						200	·67				..	·12
						20	·80				..	·13
						40	·95				..	·15
						60	1·18		2240	2569	..	·23
						80	1·50				..	·32
						300	1·90				..	·4
						310	4·60	Began to crack; this piece was fairly strained, and a slight increase in the flexure would have commenced the rupture.			10	2·7
32	Black Birch, Green.	24	1·02	1·0	781	20	·05				20	·05
						40	·10				..	·05
						60	·15				..	·05
						80	·20				..	·06
						100	·26				..	·06
						20	·32	No set.	1387		..	·07
						40	·39				..	·1
						60	·49	In 3′=·50			..	·11
						80	·60	.. =·65			..	·1
						200	·80				..	·2
						20	1·00	In 5′=1·10.			..	
						240		Broke suddenly without warning.				
33	Do.	24	1·02	1·0	762·8	20	·04				20	·04
						40	·08				..	·04
						60	·12				..	·05
						80	·17				..	·05
						100	·22				..	·05
						20	·27		1387		..	·05
						40	·32	No set.			..	·08
						60	·40				..	·08
						80	·48				..	·14
						200	·62				..	·13
						20	·75	In 5′=·80				
						240		Broke like the former.				
34	Yellow Birch, Green.	24	·99	1·0	767·7	20	·023	This specimen had a slight set originally, and			20	·023
						40	·046	was placed with the concavity downwards.			..	·024
						60	·07				..	·04
						80	·11				..	·04
						100	·15		1212	1222	..	·05
						20	·20	No set.			..	·08
						40	·28				..	·08
						60	·36	In 5′=·39			..	·12
						80	·48	.. =·51			..	·12
						200	·60	Broke; deflection=1·10				
35	Do.	24	·99	·99	745·4	20	·04				20	·04
						40	·08				..	·06
						60	·14				..	·06
						80	·20				..	·06
						100	·26				..	·06
						20	·32	No set.	1458	1472	..	·06
						40	·38				..	·10
						60	·48				..	·12
						80	·60				..	·12
						200	·72	=·75 } in 5′			..	·13
						20	·85	=·95 }			..	·25
						240	1·10	Broke; deflection=1·20				
36	White Cedar, or Arbor Vitæ.	24	·99		357	20	·10				20	·1
						40	·20				..	·12
						60	·32		805	813	..	·15
						80	·47	No set.			..	·23
						100	·70				..	·5
						120	1·20	Broke.				

EXPERIMENTS CONTINUED. ENDS LOOSE.

No. of Experiment.	Names of Woods.	Length in inches = l.	Breadth = a.	Depth = d.	Specific gravity.	Weight applied.	Deflection in inches = Δd.	Remarks.	Value of S from formula $S = \frac{l W}{4 a d^2}$.	Value of S′ from formula $S' = \frac{l W \sec^2 \Delta}{4 a d^2}$.	Columns of Differences. Weights.	Columns of Differences. Deflection.
37	White Cedar.	24	·99	1·0	352	20	·11					
						40	·22				20	·11
						60	·35		727	730	..	·13
						80	·50				..	·15
						100	·75	In 5′ = ·80			..	·25
						120	1·36	Broke.			..	·61
38	White Beech, Green.	24	·99	·99	718	20	·04					
						40	·09				20	·05
						60	·14				..	·05
						80	·19				..	·05
						100	·24				..	·05
						20	·29		1360	1369	..	·05
						40	·34	No set.			..	·05
						60	·45	In 5′ set = ·48			..	·11
						80	·60	·48 in 5′			..	·15
						200	·75				..	·15
						220	1·00	Broke.			..	·25
39	Do.	24	·97	·99	704	20	·04					
						40	·093				20	·053
						60	·146				..	·053
						80	·199				..	·053
						100	·25				..	·051
						20	·34	No set.	1400	1416	..	·09
						40	·43				..	·09
						60	·58				..	·15
						80	·75				..	·17
						200	1·05	In 5′ = 1·15			..	·30
						210	1·30	Broke suddenly.			10	·25
40	Red Beech, Green.	24	1·0	1·0	821	20	·02					
						40	·06				20	·04
						60	·10				..	·04
						80	·14				..	·04
						100	·18				..	·04
						20	·22				..	·04
						40	·26	No set.	1590	1634	..	·04
						60	·31				..	·05
						80	·40				..	·09
						200	·50	In 5′ = ·55			..	·1
						20	·65	In 10′ = ·75			..	·15
						40	·85	.. = 1·0			..	·2
						60	1·20	In 20′ = 1·65			..	·35
						265		Broke, deflection = 2·00			..	Broke
41	Red Beech, Green.	24	·995	·995	786·8	20	·02					
						40	·06				20	·04
						60	·10				..	·04
						80	·14				..	·04
						100	·18				..	·04
						20	·22				..	·04
						40	·26	In 5′ = ·28 No set.			..	·04
						60	·33	.. = ·35			..	·07
						80	·40	In 20′ = ·45	1736	1787	..	·07
						200	·50	In 36 hours = 1·42			..	·1
						20	1·48				..	·98
						40	1·55				..	·07
						60	1·62				..	·07
						70	1·72				..	·1
						75	1·82				..	·1
						80	1·92	Broke in half an hour gradually;			..	·1
						285	2·30	In 2′ neither this nor the last specimen broke exactly in the middle.			..	·38
42	Black Oak, Green.	24	·99	·99	956·8	20	·05					
						40	·10		1608	1643	20	·05
						60	·15				..	·05

EXPERIMENTS CONTINUED. ENDS LOOSE.

No. of Experiment.	Names of Woods.	Length in inches $=l$.	Breadth $=a$.	Depth $=d$.	Specific gravity.	Weight applied.	Deflection in inches $=\Delta d$.	Remarks.	Value of S from formula $S=\frac{lW}{4ad^2}$.	Value of S′ from formula $S'=\frac{lW\sec^2\Delta}{4ad^2}$.	Columns of Differences. Weights.	Columns of Differences. Deflection.
42	Black Oak, Green.	24	·99	·99	956·8	80	·20				..	·05
						100	·26				..	·06
						20	·32	Set = ·03			..	·06
						40	·40	In 5′= ·43			..	·08
						60	·50	.. = ·55			..	·1
						80	·65	In 20′= ·75	1608	1643	..	·15
						200	·80	In 5′= ·85			..	·15
						20	·95	.. =1·03			..	·15
						40	1·15	.. =1·4			..	·2
						260		Broke, deflection=1·75			..	Broke
43	Do.	24	·975	1·0	972	20	·05	This oak is principally used for staves, it is				
						40	·10	so porous longitudinally that a small quan-			20	·05
						60	·15	tity of water placed on the top of a long			..	·05
						80	·20	rod, will in a few minutes, make its way			..	·05
						100	·25	through the pores and appear at the bottom.			..	·05
						20	·30	Set=·01			..	·05
						40	·35				..	·05
						60	·45	In 20′	1723	1768	..	·1
						80	·50				..	·05
						200	·60				..	·1
						20	·70	In 5′=·75			..	·1
						40	·85	.. =·95			..	·15
						60	1·15				..	·30
						280		Broke, deflection=1·95			..	Broke
44	Tamarack, or Larch, Green.	24	1·025	1·0	430·9	20	·05					
						40	·10				20	·05
						60	·15				..	·05
						80	·22				..	·07
						100	·29	Set=·05	936	945	..	·07
						20	·40				..	·11
						40	·50				..	·1
						160	·90	Broke, deflection=1·2			..	·4
45	Do.	24	1·02	1·03	435	20	·03					
						40	·09				20	·06
						60	·15				..	·06
						80	·21		886	894	..	·06
						100	·27	In 5′. Set=·05			..	·06
						20	·38				..	·11
						40	·52				..	·14
						160		Broke, deflection=1·15			..	Broke
46	White Pine, Green.	24	1·015	1·02	465	20	·05					
						40	·09				20	·04
						60	·13				..	·04
						80	·17				..	·04
						100	·21				..	·04
						20	·25	Weight taken off. Set=·05. Weight re-[placed, deflection same as before.	1250	1256	..	·04
						40	·32				..	·07
						60	·39	In 10′=·41			..	·07
						80	·47	.. =·50			..	·08
						200	·63	.. =·70			..	·16
						220		Broke, deflection=·85			..	Broke
47	Ditto, Seasoned.	24	·985	·99	397	71	·17					
						99	·25				28	·08
						127	·35	In 5′=·38 No set.	1137	1144	28	·1
						155	·55	In 10′=·59 Set ·07			28	·2
						183	1·00	Broke suddenly.			..	·45
48	Do.	24	·965	·98	467	71	·22	Same in 10′				
						99	·30	In 30′=·32			28	·08
						127	·42				..	·12
						155	·53	In 5′=·55 Set=·04, same weights re-	1184	1199	..	·11
								placed, deflection=·58.			..	Broke
						183		Broke in 5′. Deflection=1·4				

EXPERIMENTS CONTINUED. ENDS LOOSE.

No. of Experiment.	Names of Woods.	Length in inches $=l$.	Breadth $=a$.	Depth $=d$.	Specific gravity.	Weight applied.	Deflection in inches $=\Delta d$.	Remarks.	Value of S from formula $S=\frac{l\,W}{4\,a\,d^2}$	Value of S′ from formula $S'=\frac{l\,W \sec^2\Delta}{4\,a\,d^2}$	Columns of Differences. Weights.	Deflection.
49	Canada Balsam, Green.	24	1·01	1·0	556	20	·04				20	·04
						40	·08				..	·04
						60	·12				..	·04
						80	·16				..	·04
						100	·20	Set = 0	1188	1197	..	·07
						20	·27				..	·07
						40	·34				..	·08
						60	·42	In 5′ = 45			..	·15
						80	·57	In 10′ = 64			..	·3
						200	·87	Broke, deflection = 1·07				
50	Do.	24	1·02	1·0	541	20	·04				20	·04
						40	·08				..	·04
						60	·12				..	·05
						80	·17	No set.			..	·05
						100	·22		1058	1068	..	·07
						20	·29	No set.			..	·11
						40	·40	In 30′ = 44			..	·15
						60	·55	In 5′ = 57			..	·20
						180	·75	Broke, deflection = 1·07				
51	Hemlock, Green.	24	1·01	1·02	876	20	·04				20	·05
						40	·09				..	·05
						60	·14				..	·05
						80	·19				..	·06
						100	·25		1142	1153	..	·08
						20	·33	No set.			..	·08
						40	·41	In 5′ = ·43			..	·12
						60	·53	.. = ·58			..	·2
						80	·73	.. = ·85			..	·27
						200	1·00	Broke, deflection = 1·25				
52	Do.	24	1·01	1·02	946	20	·03				20	·05
						40	·08				..	·05
						60	·13				..	·05
						80	·18				..	·05
						100	·23		1122	1156	..	·06
						20	·29	No set.			..	·08
						40	·37	In 10′ = ·39			..	·14
						60	·51	.. = ·54			..	·14
						80	·65	In 5′ = ·75			..	·2
						200	·85	Broke, deflection = 1·35				
53	Red Pine, Seasoned.	24	·965	·99	534	71	·25	Specimen a little warped upwards.			28	·07
						99	·32				..	·05
						127	·37				..	·08
						155	·45	The curve was reduced, but specimen had no set.	1338		..	·1
						183	·55	Set in 10′ = ·05			14	·07
						197	·62				..	Broke.
						211		Broke short in 5′				
54	Do.	24	·976	·975	477·8	71	·15				28	·12
						99	·27				..	·1
						127	·37		1184	1212	..	·15
						155	·52	Set = ·03			..	·33
						183	·85	Broke in 5′, deflection = 1·85				
55	Beech, Seasoned.	24	1·0	1·0	710	71	·15				28	·05
						99	·20				..	·05
						127	·25				..	·08
						155	·33	In 2 hours = ·38			..	·11
						183	·44	In 4 hours = ·66, in 18 hours = ·80	1950		14	·39
						197	·83				..	·03
						211	.86				..	·03
						225	·89				14	·03
						239	·92				14	·03

EXPERIMENTS CONTINUED. ENDS LOOSE.

No. of Experiment.	Names of Woods.	Length in inches $=l$.	Breadth $=a$.	Depth $=d$.	Specific gravity.	Weight applied.	Deflection in inches $=\Delta\ d$.	REMARKS.	Value of S from formula $S=\frac{lW}{4ad^2}$.	Value of S′ from formula $S'=\frac{lW\sec^2\Delta}{4ad^2}$.	Columns of Differences. Weights.	Deflection.
55	Beech, Seasoned.	24	1·0	1·0	710	253	·97	In 20′=1·10			14	·05
						267	1·15				..	·18
						281	1·20				..	·05
						295	1·25		1950		..	·05
						309	1·35				..	·10
						319	1·50				10	·15
						325		Broke in 2 hours.			6	Broke.
56	Black Spruce, Green.	24	99	1·0	670	91	·20					
						127	·35	In 10′=37	1109		36	·15
						155	·48	In 10′=·58. Set=·05			28	·13
						183	1·25	Broke in 3			..	·77
57	Do.	24	·975	·995	874·8	71	·23					
						99	·35	In 10′=·37. No set.	963	967·8	28	·12
						127	·53	In 10′=·60.			..	·18
						155		Gave way directly, deflection=·85				Broke.
58	Soft Maple, Green.	24	1·01	1·02	718	71	·17					
						99	·22				28	·05
						127	·30				..	·08
						155	·37	In 10′=·40 Set=·05			..	·07
						183	·50	.. =·60			..	·13
						211	·75		1524		..	·25
						239	1·13	In 10′			..	·38
						253	1·30	In 5′=1·45			14	·17
						267	1·65	Gave way suddenly.			..	·35
59	Do.	24	1·01	1·0	649	71	·10					
						127	·22				28	·12
						155	·75	After remaining suspended 48 hours. Set =·4			..	·53
						183	·82				..	·07
						211	·92				..	·1
						239	1·05		1752	1792·3	..	·13
						253	1·20				14	·15
						267	1·30				..	·1
						274	1·35				7	·05
						281	1·45	In 10′=1·50			..	·1
						288	1·55				..	·1
						295	1·80	In 5′ gave way suddenly, deflection=1·82			..	·25
60	Do.	24	·95	1·0	659	71	·20					
						127	·30				56	·1
						155	·40				28	·1
						183	·55	In 10′			..	·15
						211	·67				..	·12
						239	·84		1807		..	·17
						253	·98				14	·14
						267	1·28				7	·3
						281	1·55	In 10′=1·60 cracked.			..	·27
						286	1·70	Broke in 3 minutes.			5	·15
61	Bitter Nut Hickory, Green.	24	1·035	1·01	926	71	·15					
						127	·33				56	·18
						155	·40				28	·07
						183	·59		1358		..	·19
						211	·80				..	·21
						225	·95				14	·15
						239		Gave way suddenly.			..	Broke.
62	Do.	24	1·02	1·0	807	71	·13	Specimen a little warped, placed convexity upwards.				
						127	·25				56	·12
						155	·30		1406		28	·05
						183	·38				..	·08
						211	·50				..	·12
						239	·75	Gave way suddenly in 5′			28	·25

EXPERIMENTS CONTINUED. ENDS LOOSE.

No. of Experiment.	Names of Woods.	Length in inches $= l$.	Breadth $= a$.	Depth $= d$.	Specific gravity.	Weight applied.	Deflection in inches $= \Delta d$.	Remarks.	Value of S from formula $S = \frac{lW}{4ad^2}$.	Value of S′ from formula $S' = \frac{lW\sec^2\Delta}{4ad^2}$.	Columns of Differences. Weights.	Columns of Differences. Deflection.
63	Bitter Nut Hickory, Green.	24	·975	·98	880	71	·10					
						127	·23				56	·13
						155	·32	$=$·38 in 5′			28	·09
						183	·45	$=$·53 in 10′			..	·13
						197	·65				14	·20
						211	·90		1632	1677	..	·25
						225	·96				..	·06
						239	1·03				..	·07
						253	1·15				..	·12
						260	1·25	Gave way in 10′, deflection $=$ 2·0			7	·1
64	Iron Wood, Green.	24	1·0	1·0	897	71	·15				56	·08
						127	·23				28	·05
						155	·28				..	·07
						183	·35				..	·08
						211	·43				..	·17
						239	·60		1896	1934·9	..	·24
						267	·84				..	·16
						281	1·00				14	·15
						295	1·15				..	·3
						309	1·45	Cracked in 10′ $=$ 1·60			..	·3
						316	1·75	Gave way in about 10′			7	Broke.
65	Do.	24	1·01	1·0	883	71	·10				56	·11
						127	·21				28	·07
						155	·28				..	·06
						183	·34				..	·11
						211	·45				..	·15
						239	·60				..	·1
						253	·70				14	·1
						267	·80		2019	2099·6	..	·1
						281	·90				..	·35
						295	1·25	In 10′, began to give.			..	·25
						309	1·50				..	·2
						316	1·70				7	·15
						323	1·85				..	·1
						330	1·95	In 15′ $=$ 2·05			..	·2
						335	2·15				5	·35
						340	2·4	Cracked, and slipped on support.			5	
66	Iron Wood.	24	1·01	1·0	858	71	·20					
						127	·35				56	·15
						155	·45				28	·1
						183	·60				..	·15
						211	·70				..	·1
						225	·85	In 5′ $=$ ·90	1485	1528·3	14	·15
						239	·95	In 20′ $=$ 1·20, and began to give.			..	·1
						249	1·25				10	·3
						254	1·68	In 30′			5	·43
						258	1·72				4	·04
						265		Broke gradually. Deflection $=$ 2·05			7	Broke.
67	Birch, Pretty Dry.	24	·94	·965	679	71	·1					
						99	·14				28	·04
						127	·18				..	·04
						155	·22				..	·04
						183	·26				..	·04
						211	·33		2525		..	·07
						239	·39				..	·06
						267	·47				..	·08
						295	·55				..	·08
						323	·67	Permanent set $=$ ·1			..	·12
						351	·85				..	·18
						365		Gave way gradually.			14	Broke.

EXPERIMENTS CONTINUED. ENDS FIXED.

No. of Experiment.	Names of Woods.	Length in inches $=l$.	Breadth $=a$.	Depth $=d$.	Specific gravity.	Weight applied.	Deflection in inches $=\Delta d$.	Remarks.	Value of S from formula $S=\frac{lW}{4ad^2}$.	Columns of Differences.	
										Weights.	Deflection.
1	Red Cedar, Pretty Dry.	24	·985	·96	546	64	·15	In these 3 experiments one end only of the Specimen was firmly secured, the other end in the support.			
						92	·20			28	·05
						120	·27			..	·07
						148	·33	Slipped.		..	·06
						176	·38			..	·05
						204	·50			..	·12
						232	·55			..	·05
						260	·60		2336	..	·05
						274	·65			14	·05
						288	·70			..	·05
						302	·75	Taking off weights. Set = ·1		..	·05
						316	·80			..	·05
						330	·83			..	·03
						347	·87			17	·04
						357	·90	Gave way very suddenly at a knot.		10	·03
2	Do.	24	1·005	·99	546	64	·1	Straight in the grain and free from knots.			
						120	·2			56	·1
						148	·28			28	·08
						176	·35			..	·07
						204	·39			..	·04
						232	·45			..	·06
						260	·48			..	·03
						274	·52			14	·04
						288	·55			..	·03
						302	·58		2429	..	·03
						316	·60			..	·02
						330	·65			..	·05
						344	·70			..	·05
						354	·75			10	·05
						364	·77			..	·02
						370	·82			6	·05
						377	·85			7	·03
						386	·90	All weights taken off. Set = ·15		9	·05
3	Black Ash, Green.	24	·995	·985	572·8	64	·1	This Specimen still wet and soft. Though the specific gravity was reduced from 814·2 to 572·8, the scale bruised the wood very much.			
						120	·3			56	·2
						176	·6			..	·3
						232	1·05			..	·45
						279	1·40			47	·35
						311	1·75			32	·35
						335	2·00		2387	24	·25
						350	2·1			15	·1
						364	2·2			14	·1
						386	2·4	Weights taken off. Set = 2·0. A very little more would have broken this, it had begun to give at the bottom.		22	·2
4	Birch, Pretty Dry.	24	·98	·985	679	71	·07				
						127	·17			56	·1
						183	·26			..	·08
						211	·35			28	·09
						239	·40			..	·05
						267	·50		2652	..	·1
						295	·65			..	·15
						323	·72			..	·07
						351	·85			..	·13
						379	·90			..	·05
						407	1·00			..	·1
						421		Gave way suddenly.		14	Broke.
5	Beech, Pretty Dry.	24	·98	·96	787	71	·15				
						127	·25			56	·1
						183	·31		2684	..	·06
						211	·40			28	·09
						239	·48			..	·08
						267	·55			..	·07

EXPERIMENTS CONTINUED. ENDS FIXED.

No. of Experiment.	Names of Woods.	Length in inches $=l$.	Breadth $=a$.	Depth $=d$.	Specific gravity.	Weight applied.	Deflection in inches $=\Delta d$.	Remarks.	Value of S from formula $S=\frac{lW}{4ad^2}$	Columns of Differences. Weights.	Columns of Differences. Deflection.
5	Beech, Pretty dry.	24	·98	·96	787	295	·65				
						323	·75			..	·1
						351	·85			..	·1
						379	·92		2684	..	·1
						407	1·00	Gave way suddenly about 1′ after weight was applied.		..	·07
										..	·08
6	Black Cherry, Pretty dry.	24	1·0	1·0	640	71	·07				
						127	·17			56	·1
						183	·25			..	·08
						211	·30			28	·05
						239	·36			..	·06
						267	·42			..	·06
						295	·48			..	·06
						323	·53			..	·05
						351	·60			..	·07
						379	·65			..	·05
						393	·70		3650	14	·05
						407	·73			..	·03
						421	·80			..	·07
						435	·85			..	·05
						449	·90			..	·05
						463	·95			..	·05
						477	1·00			..	·05
						491		Began to give way. But it required a weight of 520 to break it, which remained on some hours.		43	Broke
						520					
7	Curly Maple, Dry.	24	·97	·97	748·1	71	·10				
						127	·18			56	·08
						183	·23			..	·05
						239	·29			..	·06
						295	·37			..	·08
						323	·41	Weights taken off. Set $=$ ·03	3125	28	·04
						379	·52			56	·11
						435	·63			..	·11
						463	·70			28	·07
						477		Gave way gradually.		14	Broke
8	Rock Elm, Pretty dry.	24	·92	·94	819·5	71	·10				
						127	·25			56	·15
						183	·35			..	·1
						239	·55			..	·2
						267	·65	Set $=$ ·15		28	·1
						323	·82		3835	56	·17
						379	1·03			..	·21
						435	1·14			..	·11
						463	1·25			28	·11
						491	1·39			..	·14
						521	1·44	After 60′ $=$ 1·53. Set $=$ ·75		30	·05
9	White Oak, Dry.	24	·975	·975	660·5	71	·10				
						127	·20			56	·1
						183	·30			..	·1
						239	·40	Set $=$ ·02		..	·1
						295	·50			..	·1
						351	·60		3362	..	·1
						407	·80			..	·2
						463	1·04			..	·24
						491	1·10			28	·06
						521		Permanent set $=$ ·5		30	
10	Ditto, Green.	24	·98	·98	685	100	·15				
						200	·33	Set $=$ ·06		100	·18
						300	·58		3943	..	·25
						400	·98			..	·4
						500	1·37			..	·39

EXPERIMENTS CONTINUED. ENDS FIXED.

No. of Experiment.	Names of Woods.	Length in inches $=l$.	Breadth $=a$.	Depth $=d$.	Specific gravity.	Weight applied.	Deflection in inches $=\Delta d$.	Remarks.	Value of S from formula $S=\frac{l\,W}{4\,a\,d^2}$	Columns of Differences. Weights.	Columns of Differences. Deflection.
10	White Oak, Green.	24	·98	·98	·685	600			3943	..	
						620	2·90	Broke.		20	
11	Black Ash, Green.	24	·99	·975	531	71	·18	The wood soft, and drew a little from supports.			
						127	·37			56	·19
						155	·48			28	·11
						183	·60			..	·12
						211	·80		1965	..	·2
						239	·90			..	·1
						267	1·05	In 3′ set=1·18		..	·15
						295	1·25			..	·2
						309	1·3	Began to give, but it took 28 lbs. more to break it.		14	·05
12	Iron Wood, Green.	24	·995	·98	768·7	71	·05				
						127	·13			56	·08
						183	·20	Weight taken off. No set.		..	·07
						239	·27			..	·07
						295	·35			..	·08
						351	·47		3172	..	·12
						407	·67	Cracked at bottom.		..	·2
						463	1·00			..	·33
						491	1·08			28	·08
						521	1·20	After remaining 24 hours deflection became 1·6 and set 1·2		30	·12
13	Do.	24	·985	·98	807·7	71	·06				
						127	·11			56	·05
						183	·22			..	·11
						239	·35			..	·13
						295	·47		3172	..	·12
						351	·58			..	·11
						407	·72			..	·14
						463	·90			..	·18
						491	1·03			28	·13
						521	1·15	In 24 hours, deflection 1·40. Set=·9		30	·12
14	Bitter Nut Hickory, Green.	24	·985	·98	779·5	71	·08				
						127	·17			56	·09
						183	·25	No set.	2478	..	·08
						239	·32			..	·07
						295	·42			..	·1
						351	·55			..	·13
						407	·75	Broke in about 5′.		..	·2

III.—*On the Application of Steam as a moving Power, considered especially with reference to the economy of Atmospheric and High Pressure Steam.* By GEORGE HOLWORTHY PALMER, *M.Inst.C.E.*

ALTHOUGH the question relative to the comparative power of the Cornish and other engines has engaged the attention of this Institution, (and doubtless that of every practical engineer,) still no conclusion has been arrived at satisfactorily explaining upon what principle, the duty of the former engines so far outstrips the best reported duty of the Watt engine. The difference is truly astounding, for it is officially asserted that the average duty of ten or twelve of the Cornish engines amounted to 70,000,000 lbs. of water raised one foot high by the expenditure of one bushel of coals; and in some instances a result has been brought out so high as 100,000,000 lbs. and even 120,000,000 lbs. by the like expenditure of fuel. Even the 70,000,000 lbs. duty appears to me to be so wide of the mark, as compared with the best stated result of the Watt engine, (viz. 28,000,000 lbs.,) and the maximum effective power hitherto generally obtained by the consumption of one bushel of coals, that I am induced to address the Institution on the subject; and although the statement I herewith submit for consideration only furnishes presumptive evidence, that the statements of our Cornish friends involve some error, the proof is in my mind so powerfully conclusive, that nothing short of the actual admeasurement or weighing of the water, stating the altitude such water is raised, together with the weight of fuel consumed, will induce me to believe otherwise than that the data on which the calculations have been based are in some respect erroneous. Such is my conviction, on the evidence at present before me, and which I trust will on perusal clear me from the imputation of egotism.

I care not whether the steam applied as a motive power be what is termed atmospheric, or high pressure; whether it be worked expansively or otherwise; whether condensed in a vacuum or blown into the atmosphere; whether the engine be of the description technically denominated single, double, or atmospheric; or in fact whether the steam be applied to any other description of apparatus, human ingenuity and wisdom may devise, even in the absence of *all* friction; in short, if all the moving parts of the engine were in equilibrio and

capable of being put into motion by the least appreciable amount of power; and neither the steam nor water meets with resistance in its passage through valves, cocks, pipes, &c., and the steam undergoes no change of density, elasticity, or temperature from the instant it is generated till it has performed its intended duty; supposing these physical impossibilities could be accomplished, I conceive that 70,000,000 lbs. of water cannot be raised one foot high, by the consumption of one bushel of the best Newcastle coals, weighing 84 lbs., unless more than one cubic foot of water of 40° F. can be converted into atmospheric, or high pressure steam, by the consumption of 7 lbs. of fuel.

From the discoveries of the illustrious Italian Philosopher Torricelli we are all aware that the maximum pressure, or elasticity of the atmosphere, at the level of the sea, does not exceed a column of mercury 31 inches high, or that of water $35\frac{1}{12}$ feet in altitude, which amounts to about 15 lbs. pressure upon every superficial inch of the earth's surface.

We know that one volume of distilled water will, when converted into atmospheric steam, (barometrical pressure 30 inches,) fill a space 1694 times greater than when in its liquid state, (temperature 40° F.,) supposing such steam is kept at the precise temperature and elasticity at which it was generated. We know also that the said steam, when reduced to its original temperature, (the atmospheric pressure being unchanged,) will assume instanter its original state and bulk, or occupy $\frac{1}{1694}$th of the cubic space which it occupied when in its gaseous form.

We have evidence also (founded on the most accurate experiments, and which are not likely to be surpassed by the decomposition of coal in the furnaces of steam engine boilers, with all the "jacketing" that may be applied, in order to avoid the loss of caloric by radiation from the boiler, cylinder, &c.) that seven pounds of good bituminous coal is required (when the combustion of its inflammable matter is nearly perfected, when no excess of, or undecomposed, atmospheric air escapes through the ignited fuel, and when the least quantity of radiant caloric escapes from the steam generated) to convert one cubic foot, or $62\frac{1}{2}$ lbs. avoirdupois, of distilled water from 40° F. to atmospheric steam, at an elasticity corresponding with a barometrical pressure of 30 inches.

From the aforesaid data I will show that nature cannot herself produce a result (in the absence of all friction as before premised) amounting to one half of what

is stated to be the duty of some of the Cornish engines, if the authorities referred to can be relied on.

If therefore one cubic foot of water is convertible into atmospheric steam, by the caloric evolved by the combustion of 7 lbs. of coal, 12 cubic feet of water would require, under like circumstances, 84 lbs. or one bushel of coals. Now 12 cubic feet multiplied into 1694 cubic feet or volumes gives 20,328 cubic feet of steam, which amount represents the precise quantity of water which would occupy its place when such steam is reduced to the temperature of 40° F., and which we will suppose would rise 35 feet high, which we are aware exceeds not only the average, but the maximum barometrical column. It therefore only remains to multiply the aforesaid 20,328 cubic feet into $62\frac{1}{2}$ pounds, and that product by the assumed altitude the water is raised in a vacuum, viz. 35 feet, when we shall have the maximum effect nature is capable of accomplishing, viz. 1,270,500 lbs. of water raised 35 feet high, or 44,467,500 lbs. one foot high, with one bushel of the best Newcastle coal.

Having shewn the maximum effect that can be accomplished by the application of the atmospheric steam, generated by a given quantity of fuel, my next object will be to demonstrate that high pressure steam, when applied expansively, cannot produce so great an effect as atmospheric steam, thereby meaning to infer that no high pressure engine can perform the same amount of duty as a condensing engine, both consuming equal quantities of fuel. This is my deliberate opinion, founded on theoretical and practical experience, and which coincides with the opinion of almost every practical engineer whom I have consulted on this important subject. But what says the authority before referred to?—for in this as well as in the former question, just discussed, my arguments shall be drawn from the established laws of nature.

1st. That the sum of sensible and latent heat in steam is a constant quantity, viz., about 1172° F.

2ndly. That all matter, (steam, of course, included,) whether solid, liquid, or gaseous, from the most dense and refractory to the least ponderable, evolves caloric on compression, or increase of specific gravity, and absorbs caloric on dilatation, or when its specific gravity is diminished.

3rdly. To convert equal quantities of water of any assignable temperature, and under like pressure into steam of given temperature and elasticity, requires equal weights of fuel to be expended; but, although equal weights of water must absorb equal increments of caloric, when atmospheric steam is generated, it

does not follow that all the caloric absorbed in high pressure steam is exclusively supplied by the fuel expended. The law maintained is simply this, that the same causes produce the same effects.

4thly. That steam of two, three, or more atmospheres elasticity, is not composed of two, three, or the like number of volumes of water contained in an equal volume of atmospheric steam, when generated under the same barometrical pressure, but contains proportionably less water as the pressure under which the steam is generated increases.

In proof of the foregoing theorems, I beg to adduce the following experiments and observations.

1st. If steam be blown through and condensed in a given weight of water of any previously determined temperature, until the said water arrives at, say, 212° F., the quantity or weight of water added by such condensation, will be precisely the same, whether the steam employed be of atmospheric, double, treble, or more elasticity, thereby establishing the extraordinary fact, that all sensible caloric, exceeding 212° F., positively goes for nothing, it having become latent by dilatation. In this experiment, it is necessary to observe, that the steam condensed has lost no caloric by radiation till after such steam was converted into vapour, and the effect sought had been produced. How then a saving of fuel can arise by the use of high pressure steam worked expansively is to me an evident paradox, unless by some power utterly beyond my comprehension; the sensible caloric can be prevented from becoming latent by dilatation, which, I need scarcely add, no power can accomplish.

Again, generate steam in a suitable apparatus at, say, 500° F., and permit a jet of such steam to blow upon the bulb of a thermometer without the boiler: it will be observed, that the steam impinging thereon, registers a temperature below blood heat, (98° F.,); remove the lamp that kept up the aforesaid temperature of 500 degrees, and let the jet of steam continue to play upon the bulb of the said thermometer till it ceases to blow from the boiler, at which instant of time the thermometer within and without the boiler will indicate the same temperature, viz. 212° F. In this experiment, it is no more remarkable than true, that while the steam in the boiler is descending from 500° to 212°, that the steam blowing into the atmosphere is increasing in its temperature from 98° to 212°. Here then we have 402° of sensible caloric becoming latent by dilatation, thereby increasing the amount of latent heat in the steam of 500° from 672° to 960°, the quantity due to atmospheric steam; while in the

steam of 98° there is 1074° of latent heat. As atmospheric steam can be applied without converting sensible into latent caloric, and as the sensible caloric therein contained is of a maximum effective quantity, it follows that its application as a moving power, must, under every possible application, be more economical than high pressure steam worked expansively, on a comparison of the fuel expended in the two cases.

It remains to be explained why steam of 500° temperature, and of an elasticity equal to 44 atmospheres over and above the atmospheric pressure, denotes, when blown into the atmosphere, a temperature of 114° below that of atmospheric steam.

In one measure of steam of 45 atmospheres elasticity and of 500° temperature, there is considerably less water than is contained in atmospheric steam of 45 times its volume or cubic contents, consequently such steam, when expanded under atmospheric pressure, necessarily converts a greater portion of sensible into latent heat, than if the steam thus expanded had contained the quantity of water due to forty-five measures or volumes of steam generated under a barometrical pressure of 30 inches. Another portion of the sensible caloric lost or become latent, is due to the steam expanding beyond what its density and temperature would assign under atmospheric pressure; this result of the compressed atoms flying too far asunder is similar to that in which a spring of certain elasticity, when suddenly let go, recoils beyond its true position, being carried thither, by reason of the momentum acquired and due to its weight, elasticity and velocity; so great indeed is the effect produced by the two causes assigned, that steam of 45 atmospheres elasticity passes instantly, (when expanded under atmospheric pressure,) from the gaseous to the liquid form.

The second theorem admits of innumerable proofs, but a few examples will suffice to establish the fact, that change of specific gravity cannot possibly be effected without caloric being either given out or taken up; that is, either latent heat becoming sensible by diminution, or sensible heat becoming latent by increase of volume. Compress permanent gaseous matter, and in proportion to its increase of specific gravity will sensible caloric be evolved, let this gas cool down to the temperature of the apartment, and let the compressed gas suddenly expand to atmospheric elasticity, when the sensible caloric before evolved by compression will be instantly reabsorbed and become latent, thereby producing a diminution of temperature even sufficient to freeze water. This was a common experiment at the Portable Gas Works in this metropolis. In the Philosophical Tinder

Box we can generate with a smart stroke of the hand, sufficient sensible caloric from compressed atmospheric air to ignite Dutch tinder. Liquids as well as gaseous matter will, by increase of their specific gravity, also give out sensible caloric, as is witnessed by the admixture of about four measures of distilled water with one of concentrated sulphuric acid, when the compound will, in a few seconds, exceed the temperature of boiling water. The very familiar experiment of slaking concrete caustic lime by the application of water, and the caloric thereby evolved, is the necessary consequence of the water assuming the solid state. Solids also, as well as liquids and gaseous matter, are governed by the same law, for an expert smith will, by a few blows of a hammer upon a malleable piece of wrought iron, elicit sufficient sensible caloric to make it red-hot, so as to explode gunpowder therewith. The caloric evolved is exclusively the result of the metal's increase of specific gravity by striking the iron at right angles, by which operation the cohesion of the atoms of metal are so destroyed by separation as to require welding before the experiment can be successfully repeated: not that the fractured iron receives a new supply of sensible caloric in a latent state by being heated in the fire, as has been asserted, but by reason of the shattered particles of metal being rendered in a fit state to receive the blows of the hammer without flying to pieces, which would be the case but for the fact of the fractured metal being again united by the process of welding. Each atom of metal actually contains sufficient caloric in a latent state (when liberated by percussion or any other mode of concentrating the particles of metal) to destroy the metal's identity by converting it into a perfect oxide, as is witnessed by the combustion of the particles of iron or steel abraded by the flint, in the act of striking a light, as it is termed. The late Mr. Wedgewood, to his astonishment, elicited caloric by the friction of two incombustible substances, viz. glass and stone; but he seems to have had no idea that this phenomenon was the result of compression or increase of specific gravity by the friction and abrasion of the matter thus acted upon. Of the latter case, we have the most striking proof in the following experiment, viz., that a cast-iron bomb, when filled with water and subjected to an intense frigorific operation, does not assume the solid state (ice) till the cast-iron shell is ruptured by the combined efforts of the metal contracting, and the water (in the aggregate) expanding, thereby overcoming the cohesion of the metal, when the shell bursts, and the water instantly becomes solid; at that instant caloric is evolved; and to shew the beautiful harmonious working of nature in the chain of cause and effect, no evolution of caloric

takes place till the water is frozen, thereby shewing that a concentration of matter has taken place. The fact of water, in a concrete form, floating on water of the same temperature, is cited by philosophers as one of the exceptions to the general law—namely, that caloric is evolved with a diminution instead of an increase of specific gravity, founded on the abstract fact, that ice (and, I may add, saline solutions) at the instant of crystallizing swim instead of sink. The cause of which phenomena should be sought for in the innumerable cells or spaces charged with air; or, in the buoyancy of those cells or air-vessels in the aggregate more than compensating for the increase of specific gravity the water undergoes by congelation, thereby producing the paradox in question, viz., an evolution of caloric, and yet an apparent loss of specific gravity, judging from the abstract fact of the ice swimming upon water of the like temperature. We therefore learn the fact, that the water at the instant it assumes the solid form both contracts and expands; by the former caloric is evolved, and by the latter (not in each atom, but in the aggregate) it floats upon water of its own temperature, not because the ice is specifically lighter than the water, but by reason of air cells or vacuities before referred to. The experiment of Perkins, whereby a soft malleable wrought-iron plate, revolving at an immense velocity, not only cuts its way into a file applied thereto, but elicits such a coruscated blaze by the combustion of the steel and iron abraded, as to astonish even the scientific beholder, furnishes evidence of the result of the compound operation of friction, and consequent increase of specific gravity of the metals abraded. Not the least apparently astonishing part of this performance is, that of the hard steel file being cut by the comparatively soft malleable iron plate; but all astonishment will, no doubt, cease on remembering that the density or hardness of the file as compared with that of the revolving plate, is in a much less ratio than the area or the rubbing part of the latter, as compared to the area of that part of the file coming in contact or rubbed therewith. For example, the file is probably not twice as hard as the revolving plate, whereas the grinding surface of the latter probably exceeds the area of the file ground one hundred times; hence the wear of the file is inevitable. I cannot doubt but that the particles of wrought-iron abraded and excited into combustion, greatly exceed in number the atoms of steel. This is not discoverable on superficial observation by reason of the great diameter and increased surface of the revolving plate, viewed in connexion with the surface or quantity of the file detached in the operation.

That a soft elastic substance will wear away more dense and inelastic matter,

is verified by the well known fact that the cuticle or scarf skin of the hand wears away both cast and wrought metal hand-rails; and what appears still more astonishing, but is nevertheless well authenticated, is that of the marble steps leading to some favourite saint, having been worn quite hollow by the friction of the naked feet and knees of pious devotees.

The third theorem partakes of positive and negative qualities, for each abstractedly considered neutralizes the other; in fact, the question admits of no other than a false solution, unless the intermediate cause and effects, dilatation and the sensible caloric thereby becoming latent, form components of the question, viz. that high pressure steam, when applied expansively as a motive power, is less economical than atmospheric steam when not permitted to expand till the piston has completed its stroke. There certainly appears, at first view, something very peculiar about highly elastic steam when expansively applied, for the fuel saved is positively just so much fuel lost; paradoxical as it may appear, it is really no paradox, but is in strict accordance with the working of nature's laws; and I sincerely wish that all other supposed paradoxes could be as readily cleared up.

In practice, we observe that every additional atmosphere's elasticity steam is generated at, the time is shorter than was occupied in generating the previous atmosphere; even when equal quantities of combustible matter are decomposed, or equal increments of caloric are evolved in equal periods of time; in this case the saving of fuel accruing will be in the exact ratio to the time saved, and is exclusively the result of steam of a given number of atmospheres elasticity containing less water than is contained in the same number of volumes of atmospheric steam, the inevitable consequence of latent heat being evolved in a sensible state as the steam's density increases; which caloric, of course, increases the steam's elasticity, and is therefore the precise measure or amount of fuel saved in generating highly elastic steam, but is unfortunately lost when such steam (as will be hereinafter shewn) is applied expansively. Atmospheric steam registers a temperature of 212°, steam of ten atmospheres elasticity of 358°, twenty of 418°, thirty of 457°, forty of 486°, and that of fifty atmospheres elasticity a temperature of 510°. Here then the quantity of sensible caloric in each atom of steam of 510° temperature produces a power infinitely greater than that of steam in equilibrio with the atmosphere, which, when condensed in order to gain the atmospheric effect, is only one-fiftieth part of the power of steam at 510° temperature, although it is barely $2\frac{1}{2}$ times less temperature than atmospheric steam.

Here then is evidence of the saving of fuel, or what is the same thing, demonstration of an immense increase of power obtained by the expenditure of a given quantity of fuel; but what it amounts to in practice may readily be inferred from what has previously been advanced relative to the change of specific gravity. If less fuel is expended to generate steam of every successive atmospheres elasticity, (which every accurate experimenter knows to be the fact,) it necessarily follows that every succeeding atmosphere generated contains a less quantity of water than the preceding atmosphere or volume.

1st. Because equal quantities of caloric are required to convert equal quantities of water into steam, supposing the steam generated to be atmospheric.

2dly. Because the steam cannot increase in its specific gravity and elastic force, without converting a portion of sensible into latent caloric, and this is the intermediate cause and effect that is lost sight of; and,

3dly. Because the latent caloric becoming sensible, necessarily gives an increased elasticity to the steam through which it is diffused, and the increase of elasticity thereby produced is (as before stated) the precise amount of fuel, or caloric, saved in generating high pressure steam as compared with the generation of a like volume of atmospheric steam.

It must be particularly borne in mind that the fuel saved refers only to the steam's generation, (as before stated,) for it is one thing to generate high pressure steam, and another to apply expansively the said steam as a motive power; unless the opponents to the doctrine are prepared to prove that high pressure steam, by dilatation or diminution of specific gravity, does not convert sensible into latent caloric; or that they are further prepared to demonstrate (upon Mr. Woolf's erroneous principle) that the second dose of sensible caloric gives an elastic force to the expanded steam (when maintained at the temperature such steam was generated at) equal to the atmospheric pressure.

Steam at or above 212° temperature is as much a permanent gas as atmospheric air, unless it be subjected to a pressure exceeding its own elastic force and the temperature due to such elasticity; in which case it would be converted into the liquid state. Again, steam is known to be governed by the same law as permanent gases (relating to the law of elasticity) when dosed with caloric, over and above the temperature at which it was evolved. It therefore remains to shew (if not already proved) that the quantity of sensible caloric lost by working high pressure steam expansively, can never be compensated for by saturating such steam with a second dose of caloric.

Mr. Perkins states in the Fourth Volume of the Register of the Arts and Sciences, when treating on the subject of high pressure boilers,—" In some recent experiments I have heated steam to a temperature that would have given all the power that the highest steam is capable of exerting, which would have been 56,000 lbs. upon the square inch, if it had its full complement of water, yet the indicator shewed a pressure of less than five atmospheres."

Here then is steam exerting a force, according to Tredgold's rule, upwards of 4500 atmospheres, or, by the French philosophers, of 2567 atmospheres, giving an elastic force of nearly 38,000 lbs. per square inch, (instead of 56,000 lbs. as stated by Perkins,) reduced by dilatation to less than 70 lbs. upon the square inch. Mr. Perkins, in a still more striking experiment, generated steam at 500° temperature, equal to about 50 atmospheres, and suffered it to escape into a receiver, which was destitute of both water and steam, heated to about 1200°, which steam, for want of water to give it its necessary density, the indicator shewed a pressure of about five atmospheres.

Proof beyond this (particularly as it is in strict accordance with the laws of nature) would be almost superfluous, for here we have steam of 50 atmospheres, (should have been 46 atmospheres,) although permitted to expand in a receiver little short of red heat, indicated no more than five atmospheres elasticity; if, therefore, the second dose of sensible caloric taken up by the expanded steam had been as effective as the sensible caloric become latent by dilatation, the elasticity of the steam, instead of registering only five atmospheres should have denoted upwards of 3000 atmospheres elasticity.

The fourth theorem, viz. that high pressure steam, of say 10 atmospheres elasticity, does not contain 10 measures of atmospheric steam, or what is the same thing, ten times as much water as is contained in an equal volume of atmospheric steam, is in my mind so fully established by what has been advanced in support of the previous propositions, that it would be wasting the time of this Institution to adduce further proof. In fact, all the questions are so intimately connected, and depend so much the one upon the other, that it is difficult to discuss or prove the one without demonstrating the other.

Who, may I be permitted to ask, can believe the phenomena of nature, and at the same time advocate the principle that high pressure steam worked expansively, is attended with a saving of fuel, as compared with the effect brought out by employing atmospheric steam as a first mover? In my mind, to apply high pressure steam expansively as a motive power, even when kept at its

generating temperature, amounts to nothing more or less than gaining an advantage in order to abandon that advantage, and to produce a less effect than can be produced by going a less roundabout or circuitous way to work, and thereby subjected to all the evils consequent upon substituting complexity for simplicity, in addition to the extra capital invested, extra fuel expended, and extra labour and wear and tear of apparatus.

I had hoped the public hints that Mr. Woolf has received would have induced that gentleman, ere this, to correct the erroneous table he many years since promulgated relating to working high pressure steam expansively; the publishing of which has been productive of great evil to practical science; for in addition to Mr. Woolf's testimony of the validity of the theory then launched, may be adduced all those lecturers and authors who in their oral and written opinions do not throw out the least hint, much less attempt to prove the fallacy of the principle, viz. that steam of a given number of pounds elastic force, over and above the atmospheric pressure, when expanded as many times as it exceeds in pounds per square inch the atmospheric pressure, would, when so expanded, if maintained at the temperature at which it was generated, be equal in its elastic force to unexpanded atmospheric steam. The late Mr. Tredgold and Dr. Lardner (and probably others who have not met my eye) have exposed the fallacy of this table; and as their remarks are public property, it will redound very little to the credit of those lecturers and authors when made acquainted with the refutation, if they do not follow up the subject till the principle is exploded, as every theory ought to be that is contradicted by, or in opposition to nature's laws.

I exceedingly regret that Dr. Robison, who was aware of the doctrine of latent heat as expounded by Black, should (in his formula laid down under the article "Steam," in the Encyclopædia Britannica) confound steam and permanent gases, by assigning a law to the former (steam) that was only applicable to atmospheric and other uncondensable gaseous matter; in doing which that celebrated man lost sight of the fact that the sensible caloric becoming latent by dilatation could not be compensated for by saturating the expanded steam with the same number of degrees of sensible caloric. For instance, heat a given volume of atmospheric steam from 212° to 696°, when its elasticity will be about doubled, that is, it will maintain a pressure of about 15 lbs. over and above the atmospheric pressure; whereas steam generated at 696° temperature would give an elastic force equal to about 112 atmospheres, or multiplied into 14, equal

1568 lbs. pressure upon the square inch, by Tredgold's rule; thus then we are enabled to see and judge of the value between a given number of degrees of sensible caloric being applied to generate steam, containing its due proportion of water, and when the same amount of caloric is applied to expanded steam, necessarily deficient of that proportion of water due to its volume, and which alone can give the steam an equally effective elastic form, however afterwards saturated with caloric.

It was a saying with our late worthy President, "Give me facts, for one fact is worth a thousand arguments." If the statements given to the public by the Cornish Engineers, whose sincerity I cannot doubt, are correct, I dare not trust myself to call nature to account for the undue favouritism she confers upon our Cornish friends, by enabling them to perform results in Cornwall, that the London, Manchester, and Birmingham engineers cannot approach; and I shall perhaps be excused from expressing my surprise that the question has not been long ago set at rest, by some one erecting in London or elsewhere an engine capable of raising 70,000,000 lbs.,—I will not ask so great a favour as 120,000,000 lbs.—of water, one foot high, by the consumption of one bushel of coal. Let this be done, and I shall be the first to hail the result as one of the greatest achievements of man over matter, and give the Cornish Engineers that meed of praise they would so richly deserve, whether for the benefits conferred upon science, or upon the manufactures and commerce at large.

Before I conclude this paper, it may be necessary to refer to the fact, that an engine working the steam full power the whole stroke of the piston is found to consume rather more than double the quantity of fuel such engine expends, when working her steam expansively, by cutting the supply off from the cylinder before the piston has completed its stroke; whereas the increase of the engine's power (say a double Watt engine, of 10 horse power) is only in the proportion of 10 to 14·6 horses. Now this difference refers to steam generated at an elasticity balancing a column of mercury 35 inches high, consequently little loss of power takes place on expanding such steam, by cutting it off when the piston has made about four-fifths of its stroke, provided it be maintained when so expanded at the same temperature as the steam in the boiler, because the steam's density is only diminished one-fifth; therefore, the loss of sensible caloric becoming latent by dilatation, and the loss of power consequent thereon, are very nearly compensated for, by the expansive or increased elasticity the expanded steam undergoes, by absorbing the second dose of sensible caloric; excepting, of

course, the loss of nearly $3\frac{1}{2}$ lbs. per square inch due to the deficiency of water in steam expanded to one-fifth its volume. This is not the case with steam generated at 40 lbs. or more upon the square inch when suffered to expand as in the Cornish engines, for the loss of elasticity or power is in a greater ratio than that of steam balancing a column of mercury 35 inches high, inasmuch as steam of greater elasticity contains a less proportion of water than steam of less elasticity, for the reasons previously explained.

The causes that may lead to the loss of fuel by working an engine at full stroke, instead of expansively, I will just refer to. One or more of these combined (independently of the aforesaid cause, viz., sensible caloric becoming latent by dilatation) is quite sufficient to account for the extra quantity or loss of fuel expended, by letting the steam act full pressure during the full ascent or descent of the piston.

1st. The engine not having a constant maximum duty to perform.

2nd. A portion of the steam escaping between the piston and the cylinder.

3rd. The valves, slides, or cocks, may not be perfectly steam tight, in which case a loss of steam power or fuel is the consequence, and that in a greater ratio as the steam's density is increased.

4th. A portion of atmospheric air may enter the condenser independent of that held in solution by the water, and thus throw an additional duty upon the air-pump and engine.

5th. Steam blowing from the safety valve when the engine's duty falls below its maximum.

Any of the aforesaid, in addition to bad stoking, by letting undecomposed atmospheric air carry off a portion of the caloric generated, or by a loss of fuel, arising from imperfect combustion of the fuel passing off in the shape of dense smoke at the chimney shaft, contribute more or less to destroy the economy of the engine.

I presume that none will be found to deny, that a constant given power multiplied into a given speed of the piston, will bring out a greater result than the same power multiplied into a lesser speed, which is the precise position in which unexpanded and expanded steam are to each other; in addition to which, must be added to the latter process, (the one universally adopted) the loss consequent upon sensible caloric becoming latent by dilatation. The very fact of being able to work steam expansively, not only demonstrates that the engine is not working up to, or performing its maximum effective duty, but that

the engine is contending with a fluctuating power or resistance, as is the case with the Cornish pumping engines, and are consequently working under disadvantageous circumstances.

If the evidence herein adduced tends to establish the fact that the atmospheric steam produced by one bushel of coal, applied as a motive power, without being permitted to dilate even in the absence of all friction, and when the barometrical pressure of the atmosphere is greater than what is generally witnessed, (namely, a column of water 35 feet in altitude,) can raise no more than 44,467,500 lbs. one foot high, how is it possible for high pressure steam when worked expansively to perform more duty than atmospheric steam, or be a more economical process, if we are assured that sensible caloric becomes latent by dilatation?—that the sum of the sensible and latent heats in steam of every elasticity is a constant unvarying quantity—that all matter, by undergoing change of density, either takes up or gives out caloric—that equal quantities of caloric convert equal quantities of water into steam, whether the steam generated be atmospheric or high pressure—that atmospheric steam expands no more than 1694 times the bulk of water from which it was generated when maintained at the generating temperature—that steam of double, treble, or more elasticities, does not contain double, treble, or the like quantities of water that is contained in an equal volume of atmospheric steam—and, finally, that expanded steam, when saturated with the same amount of sensible caloric that it lost (or that becomes latent by dilatation) will never acquire the elastic force it possessed previous to dilatation. Admit all the foregoing phenomena to be in strict conformity with the laws of nature, and I cannot conceive it possible, but the conviction must follow, that working high pressure steam expansively is less economical than working atmospheric steam full pressure. Upon what principle then, permit me to ask, can the Cornish engines perform so much more duty than all the other engines. Strong, indeed, should be the evidence that ought to outweigh or cancel the foregoing laws of nature, and induce this Institution to sanction statements of duty more than double that of the best Watt engine, and still more, surpassing the limits Nature has assigned steam to perform, (under circumstances over which man has no control, the atmospheric pressure,) unless, as before premised, the Cornish Engineers can convert, with 7 lbs. of coal, more than $62\frac{1}{2}$ lbs. of water from 40° F. to atmospheric steam; and unless highly elastic steam can be applied as a first mover without converting sensible into latent caloric.

IV. *Description of Mr. Henry Guy's method of giving a true spherical figure to Balls of Metal, Glass, Agate, or other hard Substances. Communicated by Bryan Donkin, V.P.Inst.C.E.*

The principle of Mr. Guy's invention, and the apparatus he employs, will be more readily understood, by first stating, generally, that if a ball can be made to revolve rapidly in every possible direction, or in other words, if during such revolution the axis of rotation be constantly changing its angular position within the ball itself, whilst a grinding tool is applied to the surface of the ball, the most prominent parts of that surface will be first acted upon by the grinder, and by continuing the operation, the whole of the higher parts of the surface will be progressively ground off, and the ball will ultimately be left of a perfectly spherical shape.

To effect this, Mr. Guy employs two lathe mandrils, such as are used in common turning lathes, both of which are fixed in one frame or bed, with their axes exactly in a line with each other: the back centre as it is commonly called, of one of the mandrils is placed to the left hand, and that of the other to the right, thus making the collar or chuck ends to face each other. To each of these he applies a wooden chuck of about 8 or 10 inches in diameter, (for balls of 1 or 2 inches in diameter,) both of which chucks are turned perfectly flat and straight across the face, consequently the faces of the two chucks will be parallel with each other. A quick motion is given to the mandrils in the usual way by two bands, but so applied, that the mandrils are turned in opposite directions to each other, and with equal velocity.

Instead of employing both mandrils of the common construction, of a conical shape at the collar ends, such as Mr. Guy from necessity at first used, he recommends that one of them should have a cylindrical bearing at each end, so as to allow of an end motion, or of a motion backward or forward in the direction of its axis. As the chucks are employed exclusively for the purpose of giving motion to the ball, when interposed between their faces, it is necessary that it should be there compressed with such a degree of force as will make it turn, notwithstanding the friction of the grinding tool applied to its surface; and he recommends, that the proper degree of compressing force should be obtained by

means of a lever, and weight, applied to the back centre of the mandril, so as thereby to secure a constant and uniform pressure upon the ball, whatever its change of diameter may be.

Previously to subjecting any ball to this process, it must, either by turning or grinding, be brought as nearly as is practicable to a spherical shape, so as to lessen as much as possible the time and labour necessary to give it the true figure at last.

The grinding tool is a bar of brass, or copper, of about 16 or 18 inches in length, its width should be about half an inch greater than the diameter of the ball, and its thickness about one-third of its diameter. Near one end of the bar, a taper or conical hole is made, the diameter of the wider end of which is made a little larger than the diameter of the ball to be ground, so that when the latter is put into the hole, a portion of it will project beyond each side of the bar. The tool being thus prepared, the surface of the conical hole is charged with emery powder, or other suitable grinding substance; the ball is put into the hole, and introduced between the chucks, the other end of the tool being held by hand.

In order that the ball may be made to turn in every possible direction, the ball should be carried slowly and uniformly around the common axis of the mandrils in a circular path, using the grinder as a handle, and keeping it nearly in a horizontal position; the axis of rotation of the ball will therefore be successively coincident with every radius of the revolving chucks, assuming every angle in regular succession, and by pressing the grinding tool against the ball during its rotation, the emery will cut down the more prominent parts in succession, leaving it ultimately of a perfect form. Of course the farther the ball is held from the axis of the mandrils, the more rapid will be its rotation between the chucks.

Mr. Guy finds by experience, that the sides of the conical hole should form an angle with each other of about 18 degrees, he likewise observes that the narrower the grinding surface is, the better; for in the course of grinding a ball, the rubbing surface of the conical hole will be ground into a spherical shape, and as it becomes wider, the operation is retarded.

It is scarcely necessary to state that during the process of grinding, frequent supplies of oil and emery are required.

In polishing balls of hardened steel, glass, or agate, Mr. Guy uses wood as a grinding tool, charged with fine washed crocus, putty, or other suitable polishing powders, and the faces of the chucks are covered with leather.

V.—*On the expansive action of Steam in some of the Pumping Engines on the Cornish Mines. By* William Jory Henwood, *F.G.S., Secretary of the Royal Geological Society of Cornwall, H. M. Assay-Master of Tin in the Duchy of Cornwall.*

The experiments which it is my purpose to describe, were instituted with a view to the determination of the quantity of steam employed, and the mode of its distribution on the working-stroke; the duty performed with a given quantity of fuel; and the work accomplished for a certain expense.

I. *The quantity of steam employed, and the mode of its distribution on the working stroke,* were approximated to by the use of an indicator, lent me for the purpose by Robert Were Fox. It consists of a brass cylinder about 11 inches long, and 1·6 inch in diameter, open at both ends, and accurately fitted with a piston, which, when at rest, is retained near the middle of the cylinder by a spiral spring, of which one end is attached to the piston, and the other to the top of the cylinder: the upper extremity of the piston-rod is provided with a receptacle for a pencil. A tapered stopcock is fixed on the lower end of the cylinder, and is introduced into the grease-hole or other aperture in the cylinder-cover of any engine on which the indicator is placed. A light frame of wood, about 18 inches long and 4 inches wide, is fastened to the top of the indicator-cylinder, and in it a small board slides horizontally in grooves.

During the working stroke of the engine a direct motion is given to the slider by means of a string which passes over a pulley, and is connected with the radius-rod of the parallel motion. Its return is effected by the action of a counterpoise suspended over a similar small wheel. On this moveable board a piece of paper is firmly secured, and a pencil is placed on the top of the piston-rod of the indicator.

Let us now examine the operation of a single-acting engine, and the movements of an indicator fixed on it.

Every thing being at rest, the piston of the engine at the top of the cylinder, and the point of the pencil standing at A, (Pl. IV., Fig. 4,) steam is admitted from the boiler above the piston of the engine; the piston of the indicator is forced

upwards, and the line AB is described by the pencil. The engine now begins to move, but so slowly that the steam enters from the boiler more rapidly than the piston recedes before it; its pressure in the cylinder, therefore, still increases, and the piston of the indicator continues to rise: but as the working stroke of the engine commences, the slider moves in the direction GF, and the compound of the two motions generates the line BC. At C the space left by the descent of the piston is exactly filled by the steam, which enters from the boiler in the same time; the indicator-piston, therefore, does not stir; but as the engine moves, the slider still advances in the same direction, (GF,) and the horizontal line C*c* is produced. The piston now acquires speed, whilst the steam (in the boiler having expanded) enters the cylinder with diminished velocity, and is insufficient to fill the enlarging space and still retain the same density: it therefore expands, and the piston of the indicator descends, whilst the slider still moves in the same direction, and the curve *c*D is delineated. At D the steam valve, through which the steam from the boiler enters the cylinder, is closed, but the piston of the engine still descends by virtue of the elasticity of the steam already introduced, and of the momentum acquired by the moving parts of the machine. Whilst the steam expands, the indicator piston descends, and as the same horizontal motion of the slider still continues, the parabolic curve DE is made by the pencil.

The equilibrium valve, which connects the upper part of the cylinder with the lower, is now opened; and as the steam thus presses equally on both sides of the piston, the working stroke terminates, and the return stroke is made: the motion of the slider is at the same time reversed.

But when this valve is opened, the pipe which connects the top of the cylinder with the bottom, and consequently a larger space, is open to the steam, and as the slider remains for the instant stationary, the indicator-piston descends through the small vertical line EF.

The return stroke is effected by the weight of the pump-rods alone; the pressure of the steam contained in the cylinder, therefore, remains unaltered, the indicator-piston is unmoved, and the line FG, described by the pencil, is perfectly horizontal.

But shortly before the termination of the return stroke, the equilibrium valve is closed, and the steam in the cylinder not being of sufficient elasticity to sustain the load of the engine, that portion of it which is contained between the upper surface of the piston and the cylinder-cover is compressed between them

by the ascent of the former, until it is of force enough to support that weight; the return stroke is thus terminated, and the engine stops an instant or two before it commences another working stroke. This compression of the steam contained in the upper part of the cylinder, forces the indicator-piston upward, and the resultant of this gradual elevation, and of the continued retrograde motion of the slider, is the small curved line GA, the pencil at the end of the stroke returning to and standing at A.

It is evident that the form of the portion ABCcD, which is produced during the admission of steam from the boiler on the piston, must depend on the load of the engine, its size, the dimensions of the steam valve, the pressure of steam in the boiler, and the capacity of the boiler itself, and that it will, therefore, vary as these particulars may differ.

The part DzE will deviate from a true parabola only when the steam in the cylinder is heated by being surrounded by a steam-case, or jacket, or by flues containing warm air, or cooled by the influence of the circumambient medium; consequently it will be generally, pretty much alike in all cases. The same reasons and influences are equally applicable to the small and nearly vertical line EF, and to the longer horizontal one FG.

But, theoretically speaking, the curve GA is of more importance than any other portion of the figure; because it clearly shows what proportion of the working stroke is performed by the beneficial influence of working expansively.

For were the steam from the boiler admitted on the piston during the whole of the working stroke, or the pressure of the steam (if worked expansively) sufficient to support the load at the termination thereof, then the line FG, described by the return stroke, would be prolonged horizontally until it intersected an extension of the vertical line AB at x; at which point the pencil would rest at the end of the return stroke, and the instant the equilibrium valve closed the engine would stop. But it has been seen that the engine continues to move, and that the indicator-piston rises and generates the curve GA, after that valve is closed: which circumstances clearly demonstrate that the steam included between the cylinder-cover and the upper surface of the piston, is meanwhile undergoing compression; and that its elasticity both at the conclusion of the working stroke, and at the closing of the equilibrium valve, was insufficient to sustain the load. And it follows, that the portion of the working stroke which has been performed after the steam has expanded so much as to be unequal to supporting the burden, must have been accomplished by the mo-

H 2

mentum acquired in the early part of the stroke. When the pencil rests at A, the force of the steam balances the load of the engine; for the piston is never permitted to rise so far as to touch the cylinder-cover. If, therefore, from A a line be drawn parallel to FG, until it cuts the parabolic curve DE, the point of intersection z, will be at that part of the stroke where the (simple) elasticity of the steam and the load of the engine are exactly in equilibrio; and the portion zE, (described after the steam has so far expanded as to be insufficient to support the burden,) will denote the amount of benefit obtained by working expansively.

The only case in which I have been able to submit the results thus obtained with the indicator to a direct comparison with the quantity of water evaporated in the boilers was at Huel Towan, where 847·5 cubic feet of water were converted into steam. This would give 342,858 feet of steam of a pressure of 64·1 lbs. on the square inch, (or 49·1 lbs. on the inch above the atmosphere,) the mean pressure in the boiler during the experiment, or 2,153,647 cubic feet of the pressure of 10·2 lbs. on the inch*. The capacity of the cylinder-nozles and other parts of the engine which required to be filled with steam from the boiler at every stroke, was 355·57 cubic feet†, and the number of strokes made during the observations 7881. Therefore if it were indispensable for the steam on the piston, at the termination of the working stroke, to be of elasticity sufficient to sustain the load of the engine, 2,802,247 cubic feet (of a pressure of 10·2 lbs. on the inch) would have been requisite; whereas but 2,153,647 cubic feet only could be obtained from the quantity of water evaporated. Consequently but the 0·768th of the contents of the cylinder, &c., could, on an average, have been filled with steam of that force; and the remaining 0·232 of the stroke must therefore have been performed by virtue of the momentum acquired by the machine in the early part of the working stroke.

This 0·232 part of the whole is therefore the benefit obtained by working the steam expansively; although the result obtained by the indicator exhibits a still greater (about 0·388) advantage. The cause of this difference it is not very easy to assign satisfactorily. It is just possible that it may be from the fluctuating pressure of the steam (from 77·25 to 47·22 lbs. on the inch) during the experiment, giving a result differing on a mean more than 61·8 lbs. on the inch, (the force when Fig. 4, Pl. IV., was obtained,) does from the average elas-

* 10·2 lbs. was the load of the engine per square inch of the area of the piston.

† Brewster's Edinburgh Journal of Science, O. S. IX. p. 160.

ticity during the observation (64·1 lbs.). But perhaps it may more probably be, from the steam, even when expanded to a less force than 10·2 lbs. on the inch, still exercising a beneficial influence in assistance of the momentum by which the latter part of the working stroke is performed.

In a first attempt at such a comparison, which I believe is here made, it may perhaps excite no great surprise that there is not a more exact coincidence between the results obtained by these very different modes of enquiry.

II. *The duty performed with a given quantity of fuel.*—The experiments with an object to determining the duty performed with a known quantity of fuel, were made on Wilson's engine at Huel Towan; on Swan's engine at Binner Downs Mine; and on Hudson's engine at East Crinnis Mine *. These were among the best engines in Cornwall, and they were selected on account of the very varied circumstances under which they worked.

At Huel Towan the cylinder with its cover and bottom were surrounded with a case or jacket, filled with dense steam from the boiler; and these, with the steam-pipes, nozles, &c., were covered with saw-dust from 16 to 20 inches deep. The boilers had a layer of ashes, of about the same thickness, placed on them.

There was no steam-case at Binner Downs, but there were small fires on each side of the cylinder, and the flues from them were carried spirally round it; another little fire was placed beneath the steam-nozle, from the boiler, and its flue was passed over the cylinder-cover; under the steam-pipe from the boiler was a similar fire, and its smoke was conveyed round the pipe for some distance. Such parts of the engine as were not enveloped by the flues were surrounded with saw-dust †, and the boilers were covered with ashes as at Huel Towan.

The engine at East Crinnis had neither steam nor heated air passed round it; but every part which contained dense steam was surrounded with a very thick covering of saw-dust, and the boilers were protected in a similar manner to those of the other engines.

On all these the indicator was placed; and also on Burn's engine at Binner

* The engineers were respectively, Mr. Grose, Messrs. Gregor and Thomas, and Mr. Sims.

† In the progress of my experiment, the saw-dust on the cylinder-cover ignited several times. The influence exercised on the steam within the cylinders, by the media with which they were surrounded, may be discovered by an inspection of the diagrams. (Figs. 4., &c., Pl. IV.)

Downs, which is inclosed in a similar manner to Swan's engine on the same mine, already mentioned; and on Trelawny's and Borlase's engines at Huel Vor, both which have steam-cases and other coverings like that described at Huel Towan. On the duty of these no experiments were made.

TABLE I.—(CONSTANTS.)

Dimensions of the Engines, and amount of their loads.

MINES AND ENGINES.	Diameter of Cylinder.	Stroke in		Air-pump.		Diameter of valves.			Total load of the Engine.	Load per square inch of area of piston.
		Cylinder.	Pump.	Diameter.	Stroke.	Steam.	Equilibrium.	Exhausting		
	Inches.	Feet.	Feet.	Inches.	Feet.	Inches.	Inches.	Inches.	lbs.	lbs.
Huel Towan, Wilson's.....	80	10	8	36	4	8	12	16	68666·4	10·2
Binner Downs, Swan's.....	70	10	7·5	33	4	9	12	16	724·3* 51967·7	10·23
———— Burn's	64	9·33	7·75	25	4·66	7	12	13	41345	10·7
East Crinnis, Hudson's....	76	10·25	7·16	two, each 26	4·5	10	14	16	74086·1	11·4
Huel Vor, Trelawny's......	80	10	7·5	two, each 24	3·5	9	14	16	98770	14·7†
——— Borlase's	80	10	8	two, each 24	4	10	14	16	76010	12·1†

* The stroke in this pump is but 5·5 feet.

† From Captain Lean's "Monthly Reports."

TABLE II.—(VARIABLES.)

Quantities of water and steam, pressures of steam, and temperatures.

MINES AND ENGINES.	Water in Boilers*. Cubic feet.			Steam in Boilers*. Cubic feet.			Pressure of Steam in the Boilers, lbs. per square inch.			Temperature of Hot-well†.			Temperature of Condensing Water.			Temperature of Boiler-shed.			Temperature of Engine-room.			Temperature of external Air.		
	Greatest.	Least.	Mean.	Greatest.	Least.	Mean.	Greatest.	Least.	Mean.	Greatest.	Least.	Mean.	Greatest.	Least.	Mean.	Greatest.	Least.	Mean.	Greatest.	Least.	Mean.	Greatest.	Least.	Mean.
Huel Towan, Wilson's..	1096	984	1080	796	684	700	77·25	47·25	64·1	100·5°	90°	93·8°	66·5°	62°	64·72°	78·5°	74·75°	76°	77·5°	70°	75·28°	56·5°	52·5°	53·84°
Binner Downs, Swan's	686	586	636	400	300	350	74·78	58·07	67·87	98	84	89·24	56	50	52·32	108	73·75	76	73	64	66·48	56·5	49	52·56
———, Burn's			884			230			55															
East Crinnis, Hudson's	2000	1820	1920	730	550	650	36·82	26·32	31·68	90	86·5	88·2	67·5	66	67	68	64·5	66·2	64	55	61·8	50	40·75	45
Huel Vor, Trelawny's..			1164			792			47			82												
———, Borlase's....			2290			734			40															

* The boilers were, of course, always full of water and steam; and as the quantity of one increased, that of the other diminished, and *vice versâ*.

† As the pressure of the steam in the boilers increased, the temperature of the hot-well declined; so that by observing the alteration in one, that of the other could be predicted with great certainty.

NOTE TO TABLE II.

The following are the dimensions of the heating surfaces of the boilers of the three engines which were the principal subjects of my experiments. I add those of Loam's engine, on the United Mines, (with which I have been favoured by William Francis, Esq., the scientific director of that extensive mining establishment) as the only machine, the evaporation in which has been published. See Mr. Lean's Report in the *Cornwall Polytechnic Society's Transactions*, IV. (1836) p. 34.

Mines and Engines.	Area of the Fire-grates.	Surface exposed to action of the flame.	Total heating Surface exposed.
	Feet.	Feet.	Feet.
HuelTowan, Wilson's engine.	72	114	2600
Binner Downs, Swan's	48	76	1440
East Crinnis, Hudson's........	37·5	57	2500
United Mines, Loam's.........	49·5	98	2310

Loam's engine, at the United Mines, has the steam cylinder of 85 inches in diameter, the stroke in it is 10 feet, and in the pump 7·5 feet; the load is about 12 lbs. per square inch of the area of the piston, and the velocity about 4·8 strokes per minute: the elasticity of the steam employed I am unable to state. From the 2nd of March to the 5th of August, 1836, the duty was about 65 millions of pounds lifted one foot, by 100 lbs. of coal, and the evaporation by the same quantity of fuel for the same period was 15·4 cubic feet. This is a sufficient approximation to the result which I had five years previously obtained at Huel Towan.

The stroke in the cylinder of Loam's engine is estimated at 10 feet; an apparatus is fixed on it for registering the actual space passed over, and the mean for five months was 9·913 feet.

TABLE III.—(Constants.)

Dimensions of the Pumps.

	Huel Towan, Wilson's Engine.			Binner Downs, Swan's Engine.			East Crinnis, Hudson's Engine.		
	Length of Pump. Feet.	Diameter of Pump. Inches.	Temperature of water in Pump ‡.	Length of Pump. Feet.	Diameter of Pump. Inches.	Temperature of water in Pump ‡.	Length of Pump. Feet.	Diameter of Pump. Inches.	Temperature of water in Pump ‡.
First lift, or set of pumps, from the surface..................	265·75	13	71·125°	21·25*	10·	89·24° †	39·16	13	63°
Second......................	263·75	15·875	71·75	242·66	18·875	72·5	159·25	18	63
Third......................	197·75	16·125	71·875				269·66	18	63
Fourth......................	113·66	16·125	72·25				198·583	17	62·5
The deepest, which reaches to the bottom of the shaft	58·16	12·5	74	248	17·125	74	73·25	14	63

* The stroke in this pump is but 5·5 feet.

† This *lift* took its supply from the hot-well.

‡ No correction has been applied for temperature, nor for impurities contained in the

The whole loads of the three engines of which it was intended to ascertain the duty were raised perpendicularly, except the deepest lift of Wilson's engine at Huel Towan; and this was inclined to the horizon about 70°; and was connected to the engine-rod by a chain passing over two small wheels respectively of 9 and 16 inches in diameter.

The lowest lifts at Huel Towan and East Crinnis were lifting pumps, and their loads were raised by the working strokes of their respective engines. All the other pumps were forcing pumps (plungers), and their columns were lifted during the return strokes of the engines, by the weight of the rods *.

At Huel Towan, from the surface to a depth of about 534 feet, the connecting rods were 14 inches square; and from that place downward they extended about 300 feet, and were 12 inches square. They were kept in their places by thirteen sets of guides, which exposed a surface of about 53·5 square feet †.

From the surface to 396 feet deep in Binner Downs, the rods were 14 inches square; and from thence downward, there were about 258 feet of 12 inch rods; these were also retained by thirteen sets of stays, having an area of about 35·6 feet.

The rods, from the surface to 470 feet deep in East Crinnis, were 15 inches square, and thence about 200 feet deeper they were 12 inches: eleven sets of stays retained them in their places, and exposed a surface of about 38·8 feet.

Where the rods touch the stays they are protected by thin planks of some hard wood, which are always well covered with grease; they seldom fit very accurately.

water. At Huel Towan I found, by evaporation, that about 360 grains were contained in a cubic foot. The temperature is higher as we descend; which adds to the already abundant evidence of the great heat prevailing in the interior of the earth.

* The rods are usually very much heavier than the column of water, and a counterpoise is applied to balance some part of their weight: such was the case in all the engines here mentioned.

† The lengths of the *lifts* and of the rods do not coincide, because the former overlap each other in every case, in order that the higher pumps may draw out of the same cisterns into which the lower empty; and because the rods which take the different *lifts* are also doubled at the *sets-off*.

Table IV.—*Duration of the experiments, number of strokes made, materials consumed, &c.*

Mines and Engines.	Duration of Experiments.	Coal consumed.		Proportion of moisture in total weight.	Quantity of oil used (in the Engine).	Quantity of grease used.		No. of strokes made by the Engine.	Strokes per minute.	Duration of the working stroke.	Duration of the return stroke.	Interval between strokes.	Total quantity of water evaporated.	Water evaporated by 100 lbs. of coal.
		Number of measured bushels.	Total weight.			In Engine.	In Shaft.							
	1831. h. m.		lbs.			lbs.	lbs.			s.	s.	s.		Cubic Feet.
Huel Towan, Wilson's.	From 22 Nov. 2 32 P.M. To 23 Nov. 3 5 P.M.	50	5003	$\frac{1}{16}$	1 pint	17	3	7881	5·35	1·6	4·8	4·8	847·5	16·95
Binner Downs, Swan's.	From 8 Dec. 10 59 A.M. To 9 Dec. 0 2 P.M.	60	5561	$\frac{1}{10}$	1 pint	12·5	3	11258	7·49	1·34	4·23	2·4		
East Crinnis, Hudson's.	From 30 Nov. 9 28 A.M. To 1 Dec. 7 55 A.M.	34	3005	$\frac{1}{21}$	1 pint	12	5	4717	3·5	1·7	4·17	11·2		

The engines were taken without any previous preparation, and they were worked without intermission, at a speed just sufficient to keep the mines clear from water; but without permitting the pumps to draw air (*go in fork*). The workmen exercised their own discretion in the mode of working; for I purposely abstained from any other interference with them than was sufficient to satisfy myself that every thing was exposed to my notice, and fairly and honestly performed.

The results will appear in

Table V.

Mines and Engines.	Weight of the bushel of Coal.		Duty (in lbs. lifted one foot high) performed by each bushel of Coal*.		
	As taken from the heap.	When dry.	Bushel measured.	84 lbs. as taken from the heap.	84 lbs. dry.
	lbs.	lbs.			
Huel Towan, Wilson's ...	100	93·8	86,585,079	72,687,853	77,533,710
Binner Downs, Swan's.....	92·6	83·4	73,877,810	66,956,572	74,395,923
East Crinnis, Hudson's ...	88·3	84·1	73,954,606	70,003,555	73,502,699

* These numbers are on the assumption that each pump delivers the full computed quantity: but in an experiment at Huel Towan, made by Sir John Rennie and myself, the *actual* compared with the calculated delivery was as 0.924 to unity. I have repeated the comparison at the same place, with a similar result.

III.—*The work accomplished for a certain expense.*—The foregoing details supply all that is requisite for this enquiry, except the prices of the materials consumed; these were coal, at the rate of forty-one shillings for 72 measured bushels*; grease, forty-five shillings and sixpence per 112 lbs.; and oil, four shillings and two pence per gallon; at which rates the results were by

Huel Towan, Wilson's engine, 1085 tons;
Binner Downs, Swan's engine, 1006 tons;
East Crinnis, Hudson's engine, 870 tons;

lifted one foot high for the expense of one farthing.

As supplementary to the general object of the first part of this enquiry, it may be useful to compare the maxima of pressures which obtain in the cylinders, with known elasticities in the boilers; the loads of the engines remaining unchanged.

TABLE VI.—*Load of engines, and relative pressures of steam in the boilers and cylinders.*

MINES AND ENGINES.	Load on the Piston, in lbs. per square inch of its area.	Pressure of steam in lbs. per square inch.		References to Plate IV. Figs. 4 and 6.
		In the Boiler.	In the Cylinder †.	
Huel Towan, Wilson's	10·2	61·8	27	Fig. 4.
Binner Downs, Swan's	10·23	74·78	26	Fig. 5.
		58	25	Fig. 6.
———— Burn's	10·7	55	30·5	Fig. 7.
East Crinnis, Hudson's	11·4	36·8	25	Fig. 8.
		26·3	21	Fig. 9.
Huel Vor, Trelawny's	14·7	47	30·5	Fig. 10.
————, Borlase's	12·1	40	30·5	Fig. 11.

Many subjects which are yet undetermined have pressed on my attention during these experiments; among which the *steam-case* and *air-pump* are not the least important.

If any condensation take place in the case, when protected from the influence of the external air, it must be by radiation to the rarer steam within

* The bushel measure with a heaped *head* is the same which was used in Mr. Watt's time, varying only as prescribed by law.

† All the pressures mentioned throughout this paper, are absolute, and as if acting against a vacuum.

the cylinder. Now such influence, if exerted during at least two-thirds of every stroke *, would not only not increase the force of the engine by adding to the elasticity of the steam, but would render requisite the injection of a larger quantity of cold water into the condenser to effect condensation, and thereby add to the burden of the air-pump †.

There must be a point at which the resistance of vapour not abstracted, to the descent of the piston, and the pressure of the atmosphere on the air-pump whilst discharging its load, are at a minimum. Beyond this if it be attempted to reduce the force of the vapour, by injecting more cold water, the burden of the air-pump is increased by the exposure of its piston to the atmosphere for a longer time during its discharge; whilst on the other hand, if it be sought to lessen the duration of atmospheric pressure on the air-pump, by diminishing the quantity of cold water introduced into the condenser, the increased elasticity of the unabstracted vapour offers a greater resistance to the descent of the piston ‡.

This subject presents many inviting topics of enquiry; but the pursuit of them, and the earlier preparation of the details || which I have now the honour to submit to the Institution, have been prevented by more pressing occupations.

4, Clarence Street, Penzance.
August 30th, 1837.

W. J. HENWOOD.

* See Table IV.

† Brewster's Edinburgh Journal of Science, O. S. IX., p. 162.

‡ Ibid., X. p. 40.

|| A short notice of these experiments appeared in Brewster's Edinburgh Journal of Science, N. S., VI. p. 246.

VI.—*On the effective power of the High Pressure expansive condensing Engines in use at some of the Cornish Mines. By* Thomas Wicksteed, *M.Inst.C.E. Communicated in a letter to the President.*

I am induced to address you again* upon the subject of the engines used in the mines in Cornwall, from the very kind manner in which you received my last paper.

I have been lately into Cornwall, having been instructed by the Directors of the East London Water Works Company to proceed there for the purpose of examining an engine that was to be disposed of by the East Cornwall Silver Mining Company, with a view of purchasing it for the Company's Works at Old Ford. The result was, that the engine, whose cylinder was 80 inches in diameter, was purchased, and is now being removed to London, and I expect that by this time next year, it will be at work here.

While in Cornwall, I was very desirous of making such a trial of one of the engines as might be satisfactory to the London engineers, and trust that I have succeeded in my object.

I received permission to make a trial of the engine upon the Holmbush Mines near Callington, and beg to give you the following detailed account thereof.

The diameter of the cylinder was fifty inches; the sizes of the pumps or "boxes" as they are termed in Cornwall, and the height of the lifts are as follows: viz.,

	Fath.	ft.	in.		
Tye Lift	42	2	6	Diameter of Pump ...	11 inches.
Rose Lift	37	5	6	Ditto	11 ,,
Bottom Lift	8	5	6	Ditto	10 ,,

The chief points to which my attention was directed, were the quantit of coals consumed, and the actual quantity of water lifted.

I saw 94 lbs. (a Cornish bushel) of coals weighed, and had the stoke hole cleared, and the coal bins and stoke hole doors sealed; and in addition to these precautions, besides my own observation, I had one of my young men

* For previous communication, see Vol. I. of the Transactions.

stationed in the boiler-house during the time of trial, so that I am quite satisfied that no more than 94 lbs. of coals were used.

Before the trial I ascertained exactly the length of the pump stroke, which was eight feet one inch, and caused the engine to work slowly that I might have sufficient time to measure the quantity of water delivered per stroke. The water was delivered into a wooden cistern, with a valve to let the water out when I had measured it. Finding that six separate measurements produced as nearly as possible the same result, the greatest variation being 2 per cent., I then weighed the quantity of water delivered by each stroke, and found it to be equal to $285\frac{6}{10}$ lbs. I had a rod made the exact length of the stroke, namely, 8 feet 1 inch, and during the trial measured the stroke frequently; it varied from 8 feet 1 inch to 8 feet 2 inches. I have in my calculations taken the shortest length.

The diameters of the pumps, and the exact heights of the lifts, were taken very carefully.

TRIAL.

The fire under the boiler was worked down as low as could be withou stopping the engine. The pressure of steam was 40 lbs. per square inch *in the boiler*, I took the counter and the time, and then started the engine. At the end of $2\frac{1}{4}$ hours the fire was lowering, and the speed of the engine reducing, and it was necessary to have more fuel. The 94 lbs. of coal having been consumed, the engine was then stopped, and the counter again taken. It had made 672 strokes, or very nearly 5 strokes per minute. The weight of water raised was (285·6 lbs. × 672 strokes =) 191,823·2 lbs.; the height to which it was raised (was 42 fath. 2 ft. 6 in. + 37 fath. 5 ft. 6 in. + 8 fath. 5 ft. 6 in. =) 535 ft. 6 in. the weight multiplied by the height in feet is equal to 102,721,323 lbs. of water lifted one foot high with 94 lbs. of coals.

This result, however, although it shows how much water was actually raised to the surface, does not show the duty of the engine, for although, in consequence of leaks and defective valves the quantity raised is not so great as it would be were it possible to have every part perfect, nevertheless, the engine has to raise the quantity due to the areas of the pumps, multiplied by the length of the stroke, under the pressures due to the columns of water equal in height to the lifts, notwithstanding that in consequence of the defects mentioned, the whole quantity may not reach the surface; the fair mode,

therefore, of calculating the duty of the engine, during the trial, would be as follows:—

	lbs.
Weight of Column of Water 11 inches diameter, and 42 fath. 2 ft. 6 in., or 254·5 feet in height	10,498
Ditto..............Ditto...... 11 inches diameter, and 37 fath. 5 ft. 6 in., or 227·5 feet in height	9,384
Ditto..............Ditto...... 10 inches diameter, and 8 fath. 5 ft. 6 in., or 53·5 feet in height	1,824
Load upon engine	21,706

21,706 × 672 strokes × stroke $8\frac{1}{12}$ feet = 117,906,992 lbs. weight lifted one foot high with 94 lbs. of coals.

From the foregoing it will be seen that 191,823 lbs. of water, were raised 535 feet 6 inches high with the expenditure of 94 lbs. of coals, and that the duty of the engine was equal to nearly 118 millions of pounds raised one foot high. I should observe, that the engine had not been overhauled, or any thing done to it to prepare for the trial, which was not determined upon (as regarded the engine upon which the trial was to be made,) until the previous day. The boiler and flues had not been cleaned for eleven months.—My object was to prove what could be done by an engine worked upon the expansive principle, and I therefore considered that a trial for two hours would prove the capability of the engine, although, most probably, the average duty of the engine for twelve months would not be so great as it was for the short time that it was under trial. I am perfectly satisfied the trial was a fair one.

I was not able to ascertain what the pressure of steam was when it first entered the cylinder, having no indicator with me; but the Engineer, Mr. West, stated that the steam was wire drawn and reduced from 40 lbs. above the atmosphere, which was the pressure in the boiler, to 30 lbs. above the atmosphere upon entering the cylinder.

The steam was cut off at one-sixth the stroke. The steam in the jacket round the cylinder communicates directly with the boiler, and radiation is completely prevented, by the casing round the jacket; consequently a high temperature is preserved, which is absolutely necessary to obtain the full effect from the expansive force of the steam.

The following will show what effect could have been produced by the steam power, provided the engine and pump gear had worked *without* friction.

Pressure of steam when first admitted into the cylinder (30 lbs. + 14·75 lbs. − 1·5 lbs. deducted for imperfect vacuum) = 43·25 lbs.

	lbs.	
For $\frac{1}{6}$ of the stroke, the pressure was	43·250	per square inch.
When the Piston had made $\frac{2}{6}$ of its stroke the pressure was reduced to	21·625	
Ditto $\frac{3}{6}$	14·416	
Ditto $\frac{4}{6}$	10·812	
Ditto $\frac{5}{6}$	8·650	
Ditto $\frac{6}{6}$	7·208	
	6)105·961	
Mean pressure of Steam	17·66 lbs.	

The area of cylinder was	1963·5 square inches.
Mean pressure of steam per square inch	17·66 lbs.
Number of strokes	672
Length of stroke in cylinder (being one foot longer than in shaft)	9 ft. 1 in.

Power of steam 1963·5 sq. in. × 17·66 lbs. per sq. in. × 672 strokes × $9\frac{1}{12}$, length of stroke, = 211,658,702 lbs. raised 1 foot high with 94 lbs. of coals; now as the effect produced was 117,906,992, the friction of the machinery was equal to 93,751,710 lbs. raised 1 foot high, or about $7\frac{3}{4}$ lbs. pressure per square inch. As the friction of a water-works pumping engine is about $5\frac{3}{4}$ lbs. per square inch, it may be safely inferred, that an engine when working upon the expansive principle at a water-works will do more work than it does in the mines; to those who have seen the heavy pump rods, balance bobs, &c., attached to a mining engine, it will appear very evident.

In the observations I have had opportunities of making, I am very well satisfied that the engine I am about to erect at the East London Water Works will do a duty equal to at least 120 millions.

As it had been observed that the expansive principle would not answer for rotary or double engines, I was induced to make some observations upon a double engine working the stamps for breaking the copper ores at the Tincroft Mines, and I beg leave to give you the details.

The diameter of cylinder	36 inches.
Length of stroke	9 feet.
Length of crank..........................	3 feet 6 inches.
Steam was cut off in down-stroke at .	$\frac{2}{3}$ths.
Ditto .... up-stroke at	$\frac{1}{3}$rd.
Number of strokes per minute	10

The engine worked with a very equal velocity, in fact there appeared no irregularity whatever in the motion; Captain Paul, the agent of the mine, allowed me to examine the coal accounts, from which it appeared, that the average consumption of coals for the engine was 30 bushels for 24 hours.

The engine was working,—1st, a set of stamps; 2nd, a pump; 3rd, a crushing machine; and 4th, a trunking machine. The last two pieces of machinery had lately been added, and previous to this increase of machinery, it appeared from the books, that the consumption of coals was equal to 27 bushels, of 93 lbs. each, in 24 hours.

The stamping machinery worked 48 lifters; to ascertain the weight of them, I examined an account showing the weight of 26 of the cast iron heads when new, and found the average weight to be 3 cwt. 12 lbs. each, these are used until the weight by wear is reduced to 1 cwt. 2 qrs., the average weight will therefore be (3 cwt. 12 lbs. + 1 cwt. 2 qrs. ÷ 2 =) 2 cwt. 1 qr. 6 lbs. The weight of the wood work of the lifter, the iron straps, washers, &c., I found by trial to be 1 cwt. 3 qrs. 24 lbs., making the total average weight of the lifter and head (2 cwt. 1 qr. 6 lbs. + 1 cwt. 3 qrs. 24 lbs. =) 4 cwt. 1 qr. 2 lbs. or 478 lbs. The average height the stamps were lifted was 10 inches, and the 48 stamps were lifted 5 times per stroke.

The following calculations will show the duty performed by the stamping engine.

48 lifters × 478 lbs. × 0·833 feet, height lifted, × 5 times per stroke × 10 strokes per minute, × 60 minutes per hour, × 24 hours per diem, 1,376,089,344 lbs. lifted one foot high in 24 hours.

The diameter of the pump was	14 inches, or 1·069 sq. ft. area.
Length of stroke	6 feet.
Strokes per minute	10
Lift	26 feet.

Duty performed 1·069 sq. ft. × 6 ft. × 62½ lbs. per cubic ft., × 26 ft. lift × 10 strokes per minute, × 60 minutes × 24 hours = 150,087,600 lbs. raised one foot high in the 24 hours.

DUTY OF ENGINE.

1,376,089,344 + 150,087,600 ÷ 27 bushels = 56,525,072 lbs. lifted one foot high, with a bushel or 93 lbs. of coals.

The single engine at the Holmbush mine was, during the time of my experiment, doing the work of 26·48 horses; thus the experiment lasted $2\frac{1}{4}$ hours, or 135 minutes × 33,000 lbs., lifted 1 foot = 4,455,000 lbs., which would be lifted 1 foot high by the exertion of 1 horse's power in $2\frac{1}{4}$ hours. 117,906,992 lbs., ÷ 4,455,000 = 26·48 horses' power. The coals consumed were equal to 94 lbs. or (94 lbs. ÷ 26·48 horses' power ÷ 2·25 hours) = 1·57 lbs. of coals per horse's power per hour. The coals used by one of the pumping engines at Old Ford in an experiment lasting 1 hour, tried upon the 18th of February 1835, were equal to 4·82 lbs. per hour per horse's power, or three times the consumption of the Cornish engine, notwithstanding the extra friction in a mining engine.

The double engine at the Tincroft mines was doing the work of 32·11 horses; thus 33,000 × 60 minutes × 24 hours = 47,520,000 lbs. lifted 1 foot high by the exertion of one horse's power during 24 hours. The engine lifted 1,526,176,944 lbs. 1 foot high in the 24 hours; 1,526,176,944 ÷ 47,520,000 = 32·11 horses' power. The coals consumed were 27 bushels of 93 lbs. each, or 2511 lbs. ÷ 24 = 104·62 lbs. per hour ÷ 32·11 horses' power = 3·25 lbs. of coals per hour per horse's power.

Mr. Farey, in his valuable treatise on the steam engine, states at page 488, that a rotary or double engine of Bolton and Watt's construction, will require $10\frac{1}{2}$ lbs. of coals per hour per horse's power, or three times the consumption of the Tincroft double engine.

The following tables may prove interesting; the first is a chronological table exhibiting the gradual improvement of the steam engine in the course of 66 years; (the first dates and quantities have been given to me by Mr. John Taylor;) the second exhibits the average duty performed by the engines in Cornwall in 1835 and 1836, including old and new engines and all sizes.

TABLE No. I.

Date.	lbs. raised one foot high, with the consumption of one bushel or 94 lbs. of coals.	lbs. of coal per hour per horse's power.
1769	5,590,000	33·33
1772	9,450,000	19·70
1786 to 1800	20,000,000	9·30
1813	28,000,000	6·64
1814	34,000,000	5·47
1815	50,000,000	3·72
1825	54,000,000	3·44
1827	62,000,000	3
1828	80,000,000	2·32
1834	90,000,000	2·06
1836	97,000,000	1·91
Trial of Fowey Consols Engine in 1835	125,000,000	1·48

Mr. John Taylor, an authority that cannot be disputed, stated, in a lecture delivered by him to the members of the Society of Arts, that in 1829 he procured authentic accounts, from the Consolidated Mines, of coals purchased and used in 1799 and also in 1828; from Wheal Alfred mines of the coals purchased and used in 1816 and in 1825; from Wheal Towan mines of the coals purchased in 1814 and 1826; from Dolcoath mines of the coals purchased and used in 1807 and 1817; and the result of his calculations, when comparing the depth of the mines at the different periods, the water raised, and the coals consumed, shewed a saving upon the books of the mines proportionate to the improvements stated to have been made during these periods in the working of the engines.

Table No. II.

Average Duty of Cornish Engines, according to Captain Lean's Reports, 1835 *and* 1836.

No. of Engines.	Diam. of Cylinder, Inches.	Average duty, or lbs. raised 1 foot high with 94 lbs. of coals.	Average load on Piston, in lbs. per square inch.	Average No. of strokes per minute.	Highest duty, or lbs. raised 1 foot high with 94 lbs. of coals.	Lowest duty, or lbs. raised 1 foot high with 94 lbs. of coals.	Time of working, in months.
4	90	47,829,830	8·971	6·707	61,884,427	35,775,624	22
3	85	71,146,686	11·643	5·761	77,311,413	63,172,606	17
7	80	66,044,570	10·989	5·351	97,595,571	37,059,128	18
2	76	47,685,167	12·594	5·071	65,345,407	40,457,463	22
5	70	52,009,587	9·672	5·416	81,026,642	22,313,025	20
3	66	49,734,514	7·965	5·379	77,446,214	24,277,768	20
2	65	54,921,572	14·57	3·098	63,411,060	43,126,101	22
1	64	50,107,225	10·74	5·83	39,625,677	19,344,343	17
6	60	48,656,046	10·819	5·73	76,673,995	29,233,376	18
1	58	61,317,268	12·29	·945	67,115,413	55,366,495	12
1	56	38,059,440	12·826	3·452	46,509,910	30,656,541	8
1	53	44,468,465	16·	2·895	58,624,253	40,294,578	6
6	50	43,645,480	9·898	5·075	60,723,738	31,587,345	18
1	45	48,137,083	18·35	6·137	55,564,549	41,268,911	8
1	42	40,712,991	16·199	8·667	46,132,677	36,499,814	23
1	41	49,052,474	16·228	5·884	57,288,816	42,081,037	22
6	40	45,591,848	11·196	5·356	64,400,208	24,962,485	12
1	39	31,286,192	11·451	3·13	39,427,731	25,395,105	23
9	36	33,277,832	12·781	6·357	47,884,690	17,619,529	13
1	33	30,245,394	15·927	6·4	36,265,146	22,938,142	23
4	30	38,828,948	13·838	7·039	74,897,208	19,344,343	17
1	26	31,529,396	17·56	8·26	34,943,591	27,697,031	14
1	$25\frac{1}{2}$	28,248,292	17·6	11·555	32,431,160	20,773,914	23
3	24	35,377,387	13·682		47,101,689	20,562,859	21

I cannot conclude this paper without acknowledging the great attention I received from the intelligent engineers and captains of the mines in Cornwall, whom I found, as in my former visit, most anxious to give every facility to those parties who visit the county for the purpose of obtaining information; and notwithstanding their own thorough conviction of the advantages of the system they adopt, and of the truth of the statements made in the monthly reports, they were in every instance most desirous of removing the doubts that others might have, by permitting any trials to be made, and by most readily and openly giving any information that might be required.

Old Ford, August 7, 1837. THOMAS WICKSTEED.

VII.—*Description of the Drops used by the Stanhope and Tyne Railroad Company for the Shipment of Coals at South Shields. By* T*HOMAS* E. H*ARRISON*, *M.Inst.C.E.*

THE mode of shipping coals shewn by the drawings, (Plates V. and VI.,) was made the subject of a patent by the late William Chapman, of Newcastle upon Tyne, in the year 1807, and it is one of those instances in which the patentee, either from prejudice or some other cause, received little remuneration for an invention which has been the means of saving thousands to the coal owners on both the rivers Tyne and Wear; for although it was almost entirely neglected during the continuance of the patent, it shortly afterwards came rapidly into extensive general use.

Previous to the introduction of the plan now generally adopted, coals were chiefly transferred by waggons from the various collieries to the river, where they were put into keels or barges, the bottom of the waggon being let out, and the coals running down a spout or guide to the keel; in these keels they were conveyed down the river to the vessels, and cast by the keelmen into the hold of the vessel.

From these various operations and transhipments the coals received much damage by breakage, and the attendant expense was also considerable. The same system is, however, in use in some collieries at the present day; but from the various railways now in progress, which will bring all the coal to parts of the rivers at which they can be shipped at once into the vessels, there is little doubt but that in a few years a keel will hardly be known upon either the river Tyne or Wear.

During the year 1837, the quantity of coals shipped from the north of England was as follows: from Newcastle 2,868,651 tons, Sunderland 1,174,598 tons, and from the port of Stockton 1,192,353 tons, making in the whole 5,235,602 tons; of which it may be calculated that at least three-fourths are shipped by means of drops varying considerably in arrangement of the machinery, but all upon the principle of the original patent.

The advantages of the plan are, that it avoids considerable breakage to the coals, as the waggon is lowered down to the level of the deck of the vessel,

and the coal has much less height to fall; that by arranging the length of the vibrating or falling frame according to the situation, a vessel may lie in deep water at a distance from the quay and receive her cargo; and that the whole machine being self-acting, the expense of shipment is very trifling.

General description. The mode of operation will be readily understood on referring to the figures 1, 2, and 3, Plate V., which represent the general elevation, and a front and back view, and to Fig. 4, Plate VI., which shews a general plan of the whole. The waggon weighing from 28 to 30 cwt., and containing 53 cwt. of coals, is run on to the cradle *a*, which is suspended from the top of the vibrating frame *b*, (Figs. 1, 2, 3, Plate V.,) which moves on carriages *i* (Figs. 1 and 3) at its foot, and is retained in its position by means of ropes attached to the upper end. The waggon is secured in its place upon the cradle by means of two wooden chocks *kk*, (Fig. 4, Plate VI.,) and the cradle itself is fastened when in its highest position to the main gangway by a latch and pin *m*, (Fig. 4. Plate VI.) The ropes from the head of the vibrating frame are fastened to and wind upon the sheaves *f* and *g*, which are fixed upon the shaft *e*; (Figs. 2 and 4;) upon this shaft is also fixed the sheave *h*, to which is attached the rope holding the counterbalance weight *c*, and there is also upon the same shaft the brake wheel *d*, (Figs. 1 and 2, Plate V., and Fig. 4, Plate VI.,) which being of 16 feet diameter, and having a brake acting upon its whole circumference and worked by a powerful lever, gives the brakesman entire command over the whole operation.

Counterbalance. The counterbalance *c* is formed of a chain of cast iron links, which lie in the bottom of the well when the frame is in its highest position, as shewn in Fig. 1. Links of wrought iron have also been used, but the cast iron are found to answer best. The weight of the counterbalance is about 5 tons.

Cost. The cost of one of these drops, including all machinery, timber, and iron work, but exclusive of masonry and gangway, is about £500. Great steadiness is given to the machinery by two heavy piers of masonry, the four main legs (upon which the whole of the superstructure rests) being half let into them, and firmly bolted together by strong bolts running through them.

The great length of the vibrating frames enables vessels to receive their cargoes at these staiths, whilst lying in a depth of water varying from 13 to 16 feet (at the different drops) at low water of a spring tide.

Powers of shipment. One of these drops is capable of shipping one Newcastle chaldron of coals of 53 cwt. every minute, but this is never required in practice, as

the coals cannot be trimmed in the ships so fast, the usual work being from 25 to 35 chaldrons per hour.

Mode of operation. The waggon being placed upon the cradle *a*, and the cradle being released from the gangway by taking out the pin *m*, (Fig. 4, Plate VI.,) the brakesman eases the brake from the brake wheel by raising the handle *d*, (Fig. 1, Plate V.,) and the vibrating frame *b*, with the waggon suspended in the cradle, begins by its gravity to descend. As the waggon descends, the counterbalance ring weights *c* are gradually lifted from the bottom of the well, the rope sustaining them winding on to the sheave *h*, as the ropes sustaining the vibrating frame are unwound from the sheaves *f* and *g*.

The waggon having arrived at the proper point, and the coals being discharged into the vessel by a man who descends with the waggon for that purpose, the counterbalance weight has then the preponderance, and by its gravity brings the vibrating frame and light waggon back to its original position.

The weight of the counterbalance is so nicely adjusted, that either the loaded waggon in its descent, or the light waggon ascending, will move at any angle at which they may have stopped. The brakesman has also ample power to stop the waggon at any point he may require, or even, in case of accident to the counterbalance weights, to hold the loaded waggon suspended.

The general arrangement of the whole differs from that of any drops erected either upon the Tyne or Wear.

VIII.—*On the Principle and Construction of Railways of continuous bearing.* *By* JOHN REYNOLDS, *A.Inst.C.E.*

THE conditions essential to a good railway may be defined as being,

1st. That it should be the closest practicable approximation to a perfect plane of perfect stability.

2d. That it should be adapted to prevent or neutralize vibrations from the impacts of imperfect cylinders rolling on imperfect planes (perfection in the surfaces of wheels and rails being unattainable in practice).

3d. That it should possess the greatest degree of durability, and the greatest facility of being repaired, which are compatible with the first two conditions.

The objects and advantages of continuous bearings will be rendered more apparent by examining in what respects isolated bearings appear to be inadequately adapted to fulfil the above conditions.

As regards the FIRST CONDITION, it may be observed, that a railway with the latter kind of bearings consists of an alternation of rigid points of support and intermediate flexible spaces; the consequence of which is, that the carriages passing along it alternately descend below, and are projected above the mean or true line of progression*. This diversion of the momentum from the straight course which it has so strong a tendency to maintain, occurring as it does 500 to 600 times in a minute, occasions a series of rapid concussions on the rails near to, or on the points of support, the severity of which is in proportion to the degree of the deviations from a straight course, the rapidity of their occurrence, and the solidity of the supports. In like manner the outward pressure of the wheels, occasioned by their being in a slight degree conical, deflects the rails sidewise between their fixed points, thereby producing a to and fro lateral motion in the carriages.

The supports being independent of each other, renders it impracticable to maintain them at exactly the same height, differences in the stability of the sub-

* Professor Barlow has shewn, in a Report to the Directors of the London and Birmingham Railway Company, that the deflection of rails between their points of support, occasions a considerable resistance to the progress of carriages upon them at high velocities.

soil, and in the degree in which it and the ballast are consolidated by the workmen, must occur, and slight variations in the rails must preclude equality of pressure and concussion on the blocks. When a block has sunk in ever so small a degree below those next adjoining it, one of these things must happen, either the rail will be held down in permanent flexure, or its efforts to regain its previous position will loosen it from the chair—loosen the chair from the block,—or hold the block in suspension.

When a rail is deflected between two chairs, they act as fulcra, by means of which the rail (or the weight causing its flexure) lifts or strains upwards the chairs next beyond them—thus each wheel in its progress successively strains up and presses down every chair it passes over, which must evidently, more or less rapidly, wear and loosen all parts of the structure.

It is evident, that the above described evils have a tendency to produce and aggravate each other. To them the greater portion of the repairs of ways and carriages is attributable.

In regard to the SECOND CONDITION, blocks of stones weighing $\frac{1}{4}$ of a ton each, must act rather as anvils than as neutralizers of impacts.

In regard to the THIRD CONDITION, the action of the rails, chairs, and blocks on each other, cause the chairs to get loose, their nail-holes becoming larger, and the nail-heads becoming less, by wear. The great height of the top of the rail above the base of the blocks, renders the latter easily tilted by the lateral action of the wheel flanges—the displacement of the blocks, from this cause and from irregular sinking, can only be repaired by digging out the ground all round them, in order to ram additional ballast under them.

The inadequacy of isolated bearers to fulfil the above stated conditions having been pointed out, it has now to be shewn in how far the continuous bearing principle, under the mode about to be described for reducing it to practice, is adequate to the purpose.

This mode consists in placing on and in a bed of "ballast" or gravel, trough-shaped bearers of cast iron connected end to end by overlap or inflexible joints. The bearers may either have the rail cast on and with them, (as shewn in Figs. 1 and 2 of Plate VII.) or have sills of wood inserted in them, (as shewn in the subsequent figures,) on which sills, rails of wrought iron, are supported throughout their whole length; the rails, sills, and bearers "breaking joint" with each other, so that the joinings of no two of them occur in the same place; they are compressed and held together by bolts or clamps, so as to

form an uniform and entire structure of the whole line, the continuity of which, therefore, can only be broken by the three materials being fractured at the same place. (See Plate VII.) This continuity causes them to be unaffected by any slight variations in the firmness of the ground which supports them, just as a beam resting upon springs of various force, would be supported by them all collectively, though pressing upon each in proportion to its individual power of resistance, whereas if a separate portion of the beam rested on each spring the several portions would assume different levels.

In investigating the effects of this mode of construction, it is desirable that the following points should be borne in mind, viz.:

1st. That gravel or ballast is a material which will not slip away from pressure like quicksand, but will become more and more hard or dense in proportion to the pressure acting upon it, till it finally resists it, however severe it may be.

2d. That ballast being non-elastic, or practically so, will retain any degree of density it may have acquired from pressure or concussion, after the force which has produced it is withdrawn, and be incapable of further condensation by any subsequent force which does not exceed that which had previously acted upon it.

As regards the fulfilment of the FIRST CONDITION, (see Fig. 11,) if pressure were applied to the rail forcing the bearer downwards, it would move and compress the ballast in the directions of the plain and dotted lines, or at right angles to the sides of the bearers.

If pressure were applied by rollers or beaters in the directions of the arrows, the ballast would still be compressed in precisely the same manner, for the plain arrows and plain lines, and the dotted arrows and dotted lines indicate similar or parallel directions.

If the bed of ballast were of exactly similar quality and thickness throughout, and its foundation equally solid, it is evident, that any amount of vertical pressure applied equally to all parts of the bearers would make them sink equally, until they were supported in all parts by ballast of the density due to the pressure, so also, if sufficient pressure were equally applied to all parts of the ballast in the direction of the arrows, (additional material being supplied to keep the height of the ballast undiminished by its compression,) the bearers, without sinking, would be supported in all parts by ballast, of the density due to the pressure so applied.

Supposing (as usually will be the case) the ballast to be of variable thickness and quality, and the sub-soil of unequal solidity, then, since the sub-soil

possesses in common with the ballast the property of acquiring density proportionate to the pressure it is subjected to, it is plain that pressure in the direction of the arrows will compress the ballast or subsoil, or both, until their density will resist that pressure, and (the depressed surface of the ballast being restored to its proper height by additional material) the bearers will be supported in every part by ballast of equal density, as in the previously mentioned case.

It thus appears, that whatever may be the circumstances of the ballast and sub-soil, they will easily be made to afford a similar and permanent support to all parts of the bearers, and it has next to be shewn, that the density or hardness of ballast which may be thus attained, is sufficient to resist the greatest pressure or concussion which can be imposed upon it by carriage wheels on the rails.

If it be assumed that the weight of a wheel would be diffused longitudinally by the rail and bearer to an extent equal to only double their united vertical depth, or (if Fig. 5 be taken as an example) to 10 inches on each side of the point of pressure, it would be sustained by a horizontal area of 220 square inches, or the intensity of the pressure on a square inch would be $\frac{1}{220}$ of the incumbent weight; hence, if by means of rollers or beaters, a pressure or percussion equal to $\frac{1}{4}$ of a ton on a square inch, were applied to the ballast in the direction of the arrows, it would thereby acquire a density, capable of resisting a pressure or concussion on the rail, equal to 50 tons; whilst the weight on a wheel must be limited probably to less than 5 tons, to avoid laminating the surface of the rails.

It can hardly be doubted that a pressure on the rails would be diffused longitudinally by them and the bearers to a much greater extent than has been assumed; (probably to the extent of 3 feet on each side of the point of pressure;) and it is certain, that a much greater force than $\frac{1}{4}$ of a ton on a square inch would be easily applied by rollers or beaters. Coach wheels apply a pressure exceeding this intensity to the surface of the common roads.

It should be observed, that by the divergency of the directions in which the bearers compress the ballast, (as shewn by the dotted lines, Fig. 11.,) and by the lateral cohesion of the particles of ballast to each other in consequence of such compression, the weight on the rails is diffused over a base, the breadth of which increases with its depth below the surface of the ballast.

The foregoing are the grounds on which the *vertical stability* of the railway is believed to be established; its *lateral* stability may be deduced from the following considerations :—

1st. By the rectangular shape of the bearers*, the vertical support they obtain from the ballast is rendered equally operative as a lateral support.

2d. The height of the rail above the base afforded by the bearers (or their width) is only one fourth of that base; and even this proportion may be diminished to any desired degree by extending the outer sides of the bearers, or those which have to resist the lateral action of the wheel flanges, whereby both the breadth or base of the bearers on that side is increased, and the vertical height of the rail above it, is diminished. (See *d*, Fig. 14.)

As the lateral force applied by carriage wheels is always accompanied by a still greater force acting vertically, the resulting force must necessarily act in a direction much nearer to the vertical than 45°, or than at right angles to the sides of the bearers.

No lateral vibration or oscillation can be produced by the passing of carriages; for their weight, by pressing the rectangle of the bearers into a coinciding angle of hard ballast, must hold them steady, that is, since their support acts as much laterally as vertically, they are as incapable of motion in the one direction as in the other.

The SECOND CONDITION is considered to be complied with by means of the sills of wood which are inserted between the rails and the bearers.

As a further security against vibration where the rails are fastened down

* This form, as compared with a flat base, affords the following great advantage. In beating or ramming ballast under the angular base, (in the direction of the arrows Fig. 11,) only one half of the force applied operates to lift the bearers upwards, whereas if the base were *flat*, the *whole* force would thus operate; hence if the weight and stiffness of the bearers were equal in both cases, the former would permit, without being raised, double the density to be given to the sustaining ballast which the latter would.

It having been supposed that the angular base of the bearers is a wedge, and will sink into the ground more easily than a flat base of equal breadth, the following observations are offered on the subject.

A rectangle is not mechanically a wedge, inasmuch as its base, instead of being *less* than its length, is nearly double its length. Whether or not a body having an angular base can, under pressure, exert a separating force on a substance in which it is embedded, must depend upon its own friction against, or adhesion to, that substance, and on the friction or cohesion of the particles of that substance in respect to each other; hence it is evident that a rectangle of cast iron could not exert a separating force on a bed of compact gravel, and still less on a bed of angular and interlocking stones. It might farther be shown, that (the breadth of base being the same) the more acute the angle of the bearer, or in other words, the *longer the sides of the wedge*, the greater would be its resistance to a depressing force.

by clamps, pieces of wood are inserted under the clamp-heads, causing the rails to be in contact exclusively with wood.

In explaining the degree in which the plan fulfils the THIRD CONDITION, the first point to be noticed is that of durability, which is expected to be obtained on the following grounds.

1st. Its strength and stability depend mainly on the cast iron bearers, which not being subject to corrosion, as wrought iron is, may be considered as indestructible.

2d. The timber, from its small dimensions, can be easily saturated with matter preventive of decay, whether by being boiled in tar *, &c., or soaked in Kyan's solution of corrosive sublimate.

3d. As the office of the timber, after the road is permanently settled, will be merely that of a cushion to neutralize vibration, its efficacy will be but little diminished by its partial decay.

4th. The timber being confined in a stiff iron case, cannot derange the line by shrinking or warping, neither can it be split or bruised by the flanges of wheels which may get off the rails.

5th. The contraction and expansion of the rails and bearers can take place without causing them to slide or rub against either the nuts or heads of the

* The application of tar, oil, &c., to wood in the ordinary manner can merely preclude the *ingress* of additional air and moisture, whilst it tends to confine in the wood the air and moisture it may contain at the time of the application. But if wood be immersed in oil or tar, and heated till it has throughout acquired as great a degree of heat as will not be injurious to its texture, (probably about 300°,) nearly all the air and moisture it contains will be driven off, and the small portion remaining in the pores and cells will be highly rarified air and steam, which, on cooling, would be condensed into perhaps $\frac{1}{1000}$ part of its volume; (depending on the proportions of air and moisture the wood may have contained, and on the heat applied to it;) therefore, if *the wood be cooled whilst* submerged in the fluid, the pressure of the atmosphere (to which mechanical pressure might be added) will force the tar or oil, &c., into its exterior pores, and probably compress the cells or pores into which the tar, &c., is too viscid to penetrate. The exterior pores of the wood will thus, as experiment has shewn, be imperviously closed against the entrance of air or moisture.

This process could be applied with most facility to timber of small dimensions. It would be less expensive than Kyan's process, and may perhaps prove a more permanent preventive of decay, since it wholly excludes moisture, the admission of which into the kyanized wood may give rise to decay, nowithstanding the change produced in the sap, and it certainly occasions the sills to swell and shrink as the weather changes from wet to dry, which is very objectionable.

bolts, whereby a certain amount of wear and consequent loosening is avoided. The motion from expansion and contraction will merely produce a very slight swaying or radial motion in the bolts, which their flexibility and the size of their holes will readily permit, and which will be too minute to affect their vertical length in any detectable degree. (See Figs. 4 and 8.) Figures 6 and 7 exhibit a mode of fastening in which clamps affixed to the bearers in the manner of a "lewis" are substituted for bolts; and they also readily permit the contraction and expansion of the rails; and in order that the closing and opening, thus caused, of the spaces between the ends of the rails, may be equal at every joint, it is desirable that the *middles* of the rails should be fixed to the wooden sills by means of screw bolts or spikes.

6th. To preserve the ballast from being softened by water, the rain which may fall on the rails and bearers is collected and carried off by the channels in the sides of the bearers, and by the spouts, (shewn in section in Fig. 10,) also the ballast under each line is laid in a raised ridge, and therefore open to drainage on both its sides; in addition to which, the ballast under the bearers forms a drain throughout. (See Fig. 11.)

The "facility of being repaired," which the plan possesses, is the last point to be noticed.

Since all parts of the structure are so combined together as to be incapable of motion in respect to each other, the only cause of derangement to which it appears to be exposed, (and this in common with all other plans,) is the sinking of the sub-soil. Those cases of subsidence which can be provided for in the mechanical construction of a railway, may perhaps be considered as of three classes.

1st. Those which, although of small extent, occur suddenly, as the slipping of a portion of embankment.

2dly. Those which occur gradually and are so extensive in length as to form a curvature, with which the flexibility of the railway will allow it to coincide from its own weight.

3d. Those which occur gradually, but are so limited in length as to form a curvature with which the railway can only coincide when depressed by an incumbent weight.

The evils of the first case can only be mitigated in their degree; and the means of mitigation which this plan affords, consist in its longitudinal con-

nexion, its lateral stiffness, and in its admitting tie-bars to be readily applied to it at any time.

The most convenient and ready mode of applying them is shewn in Fig. 14. Spaces or notches about two inches wide being cut in the portion of the sills which projects above the bearers, the tie-bars are passed under the rails, and their hooks (or ends bent at right angles) are then turned downwards so as to take hold of the bearers. They can be applied or removed with great facility.

Fig. 12. Shews a mode of applying wooden tie-bars, which being level with the middle of the road between the rails, may be used where horses work on the line.

In comparing this plan of railway as connected with tie-bars, (of whatever kind,) with a railway whose wooden sleepers act as ties, it must be obvious, that the lateral stiffness, firm longitudinal connexion, and imbedment in the ground, of the former, must enable it to oppose a much greater (at least, a ten-fold greater) resistance to being moved *sidewise*, than the flexible rails, and unconnected sleepers lying on the surface of the ground, of the latter plan, can oppose to the sleepers being moved *endwise.*

The second case requires simply, that the railway should be restored to its proper level by beating or rolling additional ballast under the bearers, and this may be very easily done, since the structure possesses a degree of vertical flexibility which, though very limited, is yet sufficient to allow it both to sink into gradual curves, and to be raised to its previous position, without any disconnexion of its parts, or deterioration of its properties. Portions of the line may be successively raised by levers or screws to the required height, and ballast be driven into the space between the bearers and the bed from which they have been lifted.

The occasion for this kind of repair will, of course, wholly cease when the sub-soil and ballast have attained permanent solidity, similar to that of a good turnpike road.

The third case differs from the second only in this respect, that the bearers not being in contact with the ballast, except when they are depressed by an incumbent weight, the space between them and it is visible on the surface, and it only requires that such space should be filled up by beating or rolling ballast into it; sleepers or bearers having flat bases beneath the surface of the ballast,

would, in such case, expose the fact of the ballast being sunken, only whilst they were depressed by a weight upon them.

The exposure on the surface of the ballast of any the smallest degree of the third case of subsidence, is an advantageous consequence of the rectangular form of the bearers, to which may be added, that the remedy is applied at the surface without disturbing the consolidated ballast.

With respect to such repairs as wear and decay may render necessary, the plan allows the rails and wooden sills to be removed and replaced without disturbing the bearers, or the foundation on which they rest.

The foregoing pages explain the objects of a continuous-bearing railway, and the mode of construction which is believed to be the best calculated to attain them; there still, however, remain to be added, a few remarks on the details.

Figures 1 and 2 shew the rails and bearers combined in one piece of cast iron, as laid on Chatmoss of the Liverpool and Manchester line in April 1836*.

The high elasticity of cast iron, and its liability to slight defects in its surface, render it ineligible for railways on which the traffic proceeds with great velocity; but where only a moderate speed is required, the combined rails and bearers (Figures 1 and 2) may be used with advantage, from the little trouble and expense of laying and maintaining them.

Figures 3 and 4 shew the two modes first adopted of affixing wrought iron rails to cast iron bearers; of these, nailing down the rails (Fig. 3) has proved to be inefficient. Bolting down the rails (Fig. 4) is effectual, but the water channels as shewn in the figure are too small.

The mode of fixing the rails by clamps (Figs. 6 and 7) is much superior to that of fixing them by bolts, since the rails have no bolt holes, and need not be cut to exact lengths, but may vary 2 or 3 inches from the mean or average length required. By the intervention of a piece of hard wood between the heads of the clamps and the rails, the latter are held in contact with wood only, whereby noise and vibration will be, as far as possible, prevented. The clamps can be applied, tightened, or loosened, with much greater facility than bolts, and as the only force or pressure to which they are exposed, acts upwards, and

* The defect exhibited in this experiment is the compression of the packings which support the extremities of the small ends of the bearers, in the saddles or large ends. This arises from the packing being *solder cast in*, and which, therefore, cannot be tightened as wear or compression takes place; this is obviated by the mode of packing shewn in the Plate, Fig. 9. In other respects this piece of railway fully answers its intention.

therefore tends to tighten them in their sockets, they cannot become loose. The sockets are so arranged in the bearers, (which are 10 feet long,) as that when the latter are connected end to end in proper order, two pair of clamps with a space of 6 or 8 inches between them, occur every 15 feet, in some part of which space the ends of the rails meet. (See A B, in Figs. 16 and 17.) This requires three patterns of bearers, as regards the position of their sockets; the number and position of the sockets, however, as also the lengths of the bearers and rails, must depend upon circumstances, and the opinion of the engineer. To secure the ends of the rails from sinking or *dingeing* into the sills, or being forced out of their true line, pieces of hard wood, 6 or 8 inches long, and of the form of the hollow or bridge of the rails so as to fill it completely, are inserted with half their length in each of the adjoining ends of the rails, whereby an additional bearing surface on the sills is afforded at the rail joints, (*c*, in Figs. 6 and 15.) Pieces of iron rolled to the required form, with thin sheets of lead between them and the rails, may be substituted for the wood*. On the outside of the rails, or the side on which the flanges of the wheels do *not* run, pieces of bar iron about an inch wide and $\frac{1}{2}$ inch thick, with strips of wood under them, are placed on the flanges of the rails across their joints, and are held down by the clamps, (as shewn at *a*, in Figs. 6 and 16,) so that the rail-ends cannot rise or shake. By the above means firm and even joints are obtained, without impediment to the contraction and expansion of the rails, and without permitting them to be in contact with iron.

The most convenient mode of laying the railway, is to render the ground on which a line of bearers is to be placed equally solid by heavy rollers or beaters, so as to form a shallow trench about 2 feet wide, taking care to give its bottom a little declination towards the places (10 to 20 yards asunder) where the cross drains will intersect it; then to fill the trench to the depth of 6 or 8 inches with stones, &c., rendered firm by rollers or beetles; on this the bearers are to be placed, and broken stones and clean gravel are to be beaten or rolled under and against their sides. After a convenient length of bearers have been ad-

* If the rails be of the form shewn in Fig. 14, then at the places of their joints, notches or recesses of 4 or 6 inches wide, and $\frac{1}{4}$ to $\frac{3}{4}$ inch deep, should be cut in the timber which projects above the bearer. The bottoms of the recesses should have a slight bevel or slope transversely to the rail. Pieces of iron or hard wood made to fit these recesses, should be driven into them after the clamps or bolts near the ends of the rails have been tightened down ; this will insure a firm bearing to the rail-ends—pieces of teak wood would probably answer well.

justed by the packing pieces at the joints, and bolted together to a true level, a long straight edge should be applied to the parts on which the sills are to rest, and if any unevenness is perceptible, the hollows, however small their depth, should have strips of wood or felt, of the proper breadth and thickness, placed in them (the workmen being provided with strips of wood cut in a saw-mill to every possible variety of thickness and taper). A level bed being thus insured for the sills, whose sides are exactly parallel, (being sawn by machinery,) the rails when fixed down upon them will present a level surface.

A perfectly level bed for the sills may be obtained by filling the interior angle of the bearers (after they have been adjusted and bolted together) with Roman cement, and rendering its surface parallel with the surface line of the rails by means of a mould sliding on a properly adjusted guide bar *. (See *b*, Fig. 14.) Before the sills are placed on the cement, its surface should be smeared with coal-tar or other similar matter.

Instead of Roman cement, a slightly elastic bituminous cement may be employed, perhaps, with greater advantage; and as either kind of cement will adhere firmly in the angle of the bearers †, it may be inserted in them severally before they are laid, and its surface (whilst plastic) be reduced to an accurate level by means of a mould or scraper guided by planed grooves in a frame properly adjusted to the bearer, the effect being the same as though the angles of the bearers had been cast solid, and their surface planed by a machine.

The intervention of a board of hard wood between the rails and sills, as shewn in the plate, will not only reduce the risk of the wood being bruised, but should this eventually happen, the boards could be replaced with but little trouble or expense. They also afford the means of easily correcting any slight deviations from a true level which may be observed in the surface of the rails by the insertion of strips of wood, pasteboard, sheet iron, or felt, between them

* It having been suggested, that the cement would probably be pulverized by the weight and concussions of the engines, &c., on the rails, the following experiment was made:—the interior angle of a bearer was filled with cement, rendered level by a mould sliding on guide bars. After a few days had been allowed for it to harden, a sill of deal 3 inches thick was laid upon it, and on the sill a bar of iron $\frac{1}{2}$ an inch thick was clamped down. The bearer being placed on a stone floor, the bar of iron was violently beaten with a sledge hammer. Although the concussion thus applied very far exceeded what could be occasioned by wheels rolling on the rails, yet the cement was neither cracked nor bruised by it—also, not a single clamp was loosened.

† A few small projections or nipples cast in the interior angles of the bearers would insure the retention of the cement.

and the sills. Such boards, however, may be safely omitted, if the hollow or bridge of the rails be filled up with hard bituminous cement, since the breadth of their bearing surface on the sills would be thereby materially increased.

The rails should have bevelled ends, as shewn in the drawings; and it is desirable that one-half of their number should have their bevels cut the reverse way to that of the other half, in order that *both* lines of rails (forming one track) may be so laid, as that the flanges of the wheels (the direction in which the trains are to travel being known) may always pass *off* or *from*, and not *on to*, or *against*, the points of the bevelled ends.

The ballast or gravel should, from time to time, be rolled or beaten till it has attained the solidity of a good turnpike road. Although a rectangular form is adopted for the base of the bearers, yet no particular forms or dimensions are prescribed; these may be varied as circumstances or opinions may dictate; therefore, all that can be stated as indicative of first cost, will be the weights and quantities of materials contained in the examples adduced in the plate.

The bearers will weigh,

as shewn in Fig.	1.	140 lbs.	per single lineal yard.
do.	3.	80	do.
do.	4.	75	do.
do.	5.	112	do.

The rails will weigh about 45 to 50 lbs. per yard. The sills, (common deal, elm, or other cheap wood,) including waste, will be less than half a cubic foot per yard, or less than one third of a cubic foot if the interior angles of the bearers be filled with cement. The quantity of ballast will not exceed the half of that required for blocks, and of this about $\frac{1}{4}$th of a cubic yard per single lineal yard should be broken stone or gravel free from earth. Hence, it will appear, that when iron is at an average price, a railway on this plan would be considerably less expensive than one of equal strength on the usual plans, except in cases where blocks and ballast are unusually cheap*. The bearers shewn in Fig. 5, &c., are stronger and heavier than would be required in ordinary cases.

* The relative expense of cast iron and wooden continuous bearers can only be determined in a comparison of particular cases. It may, however, be observed, that as the stiffness of deal is to that of cast iron less than 1 to 15, (Barlow on the strength of timber, iron, &c., 1837,) bearers of equal stiffness will be of nearly equal cost. To ascertain the comparative advantages of the two kinds of bearers, would require an investigation into the value of form, occasion for repairs, durability of material, &c., for which, at present, there are no sufficient data from experience.

EXPLANATION OF PLATE VII.

Fig. 1. Is a general section of a rail and bearer combined in one piece of cast iron. A specimen of this construction is on Chatmoss on the Liverpool and Manchester railway, where it was laid in April 1836.

Fig. 2. Is a section of Fig. 1 at the overlap or inflexible joint, shewing the small end of one bearer bolted into the saddle or large end of another bearer. The construction of the joint is similar to that shewn in Figs. 8 and 9.

Fig. 3. Is a general section of the *first mode*, adopted for combining wrought iron rails with cast iron bearers. The bearers have the form of troughs, into which sills of wood are fitted. The rails are fastened to the sills by nails or spikes.

Fig. 4. Is a general section of the *second mode* adopted for combining wrought iron rails with cast iron bearers. In this the rails are fastened down by screw pins passing through them, the sills, and the bearers. The joinings are the same as Figs. 8 and 9.

Fig. 5. Is a general section of the *last and most perfect mode* adopted for combining wrought iron rails with cast iron bearers. In this, the rails are fastened down by clamps fixed "lewis" fashion in the bearers, boards of hard wood intervene between the rails and the deal sills, as shewn longitudinally in Fig. 15.

Fig. 6. Is a section in the line AB of Figs. 16 and 17, shewing the clamps at a rail joint, with the pieces of hard wood inserted between their heads and the rails. On the side on which the wheel flanges do not run, the two adjoining clamps hold down a bar of iron, which crosses the rail joint and confines the ends of the rails. In the hollow or bridge of the rail is seen a piece of hard wood or of iron (shewn longitudinally at *c*, Fig. 15,) to distribute the pressure of the rail ends over a larger area of the sills.

Fig. 7. Is an inside front view of a clamp, and of the key by which it is fixed in the dovetailed socket of the bearer.

Fig. 8. Is a section in the line DE of Figs. 15, 16, and 17, shewing the screw pins which connect the bearers, and which in conjunction with the packing pieces (Fig. 9) render their joints inflexible.

Fig. 9. Is a section in the lines FG of Figs. 15, 16, and 17, shewing the tapered packing pieces *h h*, of iron or hard wood, which support the extremities

of the small ends of the bearers within the saddles or large ends, and by which the troughs to receive the wooden sills are adjusted to an accurate correspondence before the screw pins, Fig. 8, are tightened.

Fig. 10. Is a section in the lines HI of Figs. 15, 16, and 17, shewing the spouts by which the water collected in the side channels of the bearers is discharged beyond the bed in which they immediately rest. Draining tiles may be placed under the spouts.

Fig. 11. Is a transverse section, on a reduced scale, of a portion of finished railway, shewing the foundation, or stone drain, under the bed of broken stone or hard gravel on which the bearers are supported. The arrows and lines shew that the directions in which the ballast is compressed by the bearers, and in which it is beaten or rolled under them, are the same.

Fig. 12. Is a transverse section of a portion of finished railway on embankment, having the two lines of rails connected by a tie-bar of wood.

Fig. 13. Is an end view of the tie-bar *f*, and cleat *e*.

Fig. 14. Is a section of a rail and bearer shewing a mode of applying tie-bars of iron. Spaces or notches about two inches wide being left or cut in the wood which projects above the bearers, the tie-bars are passed under the rails with their bent ends horizontal, which are then turned downwards so as to clip the bearers; *d*, shews an extension of that side of the bearer which has to resist the lateral action of the wheel flanges, whereby both the base is extended and the vertical height of the rail above it, is diminished. In this figure, the bottom or interior angle of the bearer is represented as filled with cement.

Fig. 15. Exhibits a portion of railway in longitudinal section and in elevation. *c* is shewn in section in Fig. 6; DE, in Fig. 8; and FG, in Fig. 9. R shews a rib giving additional depth and strength to the part of the bearer immediately under the joint of the rails, where, otherwise, their want of continuity would weaken the structure.

Fig. 16. Is a plan of a portion of railway shewing the position of the clamps; in respect to which, however, no particular number is prescribed. AB is shewn in section in Fig. 6; DE, in Fig. 8; FG, in Fig. 9; and HI, in Fig. 10.

Fig. 17. Is an isometrical view of a portion of railway. The letters refer to the same sections as in Fig. 16.

IX.—*Wooden Bridge over the River Calder, at Mirfield, Yorkshire, designed and erected by* W*illiam* B*ull*, *A.Inst.C.E.*

This bridge was erected for the use of the hauling horses on the Calder and Hebble Navigation, in the summer of 1835.

The chord of the arc is 147 feet 6 inches, the versed sine 11 feet. The width of the roadway is 8 feet at the abutments and 5 feet at the crown.

The arch is composed of two ribs of fir timber, with cross stays and diagonal braces. The timbers are wrought to the curve of the arch on the under and upper sides and straight in the intermediate joints. The ends abut on each other in the line of the radii, and are secured in their places by two wrought iron bolts passing through them in a vertical direction at each joint; which bolts are connected at each end by iron straps let into the wood. The ribs are also secured to each other by wrought iron bolts (having a strong cast iron washer at each end) passing through them and the cross braces in an horizontal direction. The roadway is composed of three inch deal plank, on which a coat of pitch and tar mixed with small gravel, about an inch thick, is laid, to protect the planks from the weather and horses' feet. The ribs are let into the springing stones about six inches at each end, and are wedged in with oak and the chases filled with lead.

The abutments are formed of Ashler stone unhewn, except on the beds and joints, backed with rubble laid in mortar and grouted; the wing walls which form the approaches are of rubble stone laid dry, as are also the walls of the hauling paths under the bridge.

The foundations are sunk in the silt or debris of the valley to about six feet below the ordinary surface of the water in the river, in the front of the abutments, and rise towards the back, as shewn in the drawing. (See Plate VIII.)

The footings consist of two courses of flat stone, from 8 to 12 inches thick, and from 3 feet to 5 feet each way, laid rough as taken from the quarry; no piling is used in any part.

The arch was formed and perfectly fitted in all its parts at the carpenter's yard belonging to the Navigation Company, and taken to the spot in separate pieces.

The manner of erecting the arch was very simple, and attended with trifling expense; it was as follows. Three barges were moored in the river at equal distances between the abutments, with their heads to the stream, and a temporary scaffolding of planks erected on them, on which the ribs and braces were put together a little above the chases in the springing stones, and as soon as they were firmly screwed up were lowered into their places by striking the packings from under them. The time occupied in erecting the arch was only about three days, and the planking was completed so that horses passed over in about a week.

Considering the slightness of the ribs and the length of the span, but little vibration takes place when the horses pass over it.

The arch form given to the ribs in the plan was with a view to resist the action of the wind, which frequently rushes with great force through the valley, and which it was apprehended might have the effect of upsetting so slight a structure, if erected of an uniform width of 5 or 6 feet, (which is all that is necessary for the purposes for which this bridge is erected,) and it is found to answer the intention perfectly well. The author has been several times on the bridge when severe gales of wind were acting directly on it, without observing any sensible effect.

One great recommendation to the construction of bridges of this description for similar purposes is their cheapness; the cost of this was as follows:—

	£	s.	d.
Masonry of the abutments and wing walls, including about 40 yards of towing-path wall on each side	253	15	0
The arch, including wood and iron work, and the labour of erecting, painting, &c.	418	17	5
Earth work in sinking foundations and forming approaches . .	70	16	0
	£ 743	8	5

X.—*On the Teeth of Wheels.* *By R. Willis, M.A., F.R.S., H.M.Inst.C.E., Jacksonian Professor of Natural Philosophy in the University of Cambridge.*

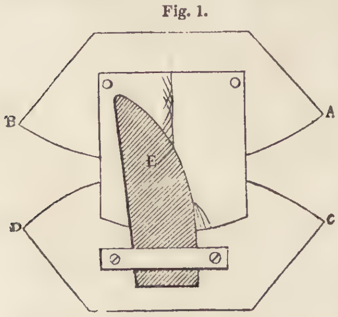
The investigation of the proper curves to be given to the teeth of wheels, has been a favourite occupation with mathematicians of the highest eminence, and the geometry of the subject may be considered to be very nearly complete.

Its application to the requirements of modern construction has appeared to me to be susceptible of improvement, and I have therefore ventured to lay before the Institution some suggestions, in which I have endeavoured to point out forms possessing properties more general than those hitherto adopted, as well as some practical methods of tracing readily the outlines of the teeth.

SECTION I. ON THE CURVES ADAPTED TO PRACTICE.

There are an infinite number of forms which will answer the conditions of enabling the teeth of one wheel to communicate equable motion to those of another, for it can be shewn that under certain limitations, if any form of tooth be given, another may be determined which will work correctly with it *. A simple instrument which furnishes a practical solution of this problem, will probably carry more conviction to the minds of practical men than the demonstrations which have been given by the writers referred to below. Let a pair of boards be prepared, having their edges AB, CD, Fig. 1, formed truly circular. Attach to one of them by any simple clamp the shape of the given tooth E, cut out in pasteboard, and to the other a piece of stiff paper secured by means of drawing pins; the shape E must be raised slightly above the surface of its board, so as to allow the paper which is appended to the other to slide under it, as is shewn in the figure. Make the circular edges of the two boards roll toge-

Fig. 1.



* Vide De la Hire, Traité des Epicycloides. Young's Natural Philosophy, Vol. I. page 176. Airy, Cambridge Philosophical Transactions, Vol. II. page 277.

ther and in each successive position draw the outline of the shape E upon the paper below it. The result of all these intersecting lines will be a bounding curve, which from the very mode of its description will touch the shape E at some point of its edge in every one of the successive positions. But as these positions were all obtained by making one circular edge roll upon the other, so it is clear, that if the new curve be cut out and made to touch E, the motion produced by the mere contact of these two curves will be exactly the same as that caused by the rolling of the circular edges, and therefore perfectly uniform.

Many forms of E, tried in this manner, will prove untractable, for some of the successive portions of its edge may cover up and obliterate parts of the curve that have been previously drawn. These are forms that fall under the limitations alluded to, but it is unnecessary here to investigate the general reasons for this effect, as the proposition in question is well known and recognized by mathematicians, although not so well understood by practical men.

From among the infinity of curves that may be offered, the epicycloids and involutes have been universally preferred, on account of the facility with which they can be mechanically described, and perhaps because they admit of ready and independent demonstrations of their possessing the properties required. But the practice has hitherto been confined to that class of epicycloids which work correctly with straight lines or circles. Teeth formed upon these principles possess this inconvenience: a wheel of a given pitch and number of teeth, say 40, if it be made to work correctly with a wheel of 50 teeth of the same pitch, will not work correctly with a wheel of 100 teeth of the same pitch. This is obvious, for the diameter of the describing circle by which the epicycloid is formed must be made equal to the radius of the pitch circle of the wheel with which the teeth are to work, and will therefore be twice as large in the second case as in the first.

In the old style of mill-work, in which the teeth of wheels always consisted of wooden cogs, this property offered no very serious impediment, although, as we shall see, it introduced some complication of method; but in the modern practice of making cast iron wheels, the objection is a very serious one. A founder must make a new pattern of a wheel of 40 teeth for every combination that it may be required to make of this wheel with others, and the same for a wheel of any other number. Besides, it often happens in machinery, that one

wheel is required to drive two or more whose number of teeth are different, and in this case the teeth cannot be correctly formed at all on the common principles; and again, the perfection of machinery is impaired from the temptation to employ in one combination patterns that have been formed for some other combination very nearly the same; for example, to make a wheel of 40 teeth that has been formed to work with one of 80, serve for a required combination of 40 with 85.

It is essential, therefore, that the teeth of wheels should, if possible, be so formed as to allow a given wheel to work correctly with any other wheel of the same pitch. Now it has long been known that involute teeth have this very property, but the objections to these teeth on the score of the obliquity of their action have operated fatally against their introduction *. I shall now, therefore, explain a method of imparting to epicycloidal teeth this property, and that without making them deviate very much from the general form that has been established by practice.

To effect this, it is merely necessary to employ a proposition well known and stated by almost every writer on the subject, namely, If there be two pitch circles touching each other, then an epicycloidal tooth formed by causing a given describing circle to roll on the exterior circumference of the one, will work correctly with an interior epicycloid, formed by causing the same describing circle to roll on the interior circumference of the other.

This proposition having been demonstrated by so many writers, it is unnecessary for me to dwell upon it longer than to remark, that they have all passed from it, to recommend for practice that particular case of it in which the describing circle being made equal in diameter to the radius of the pitch line, the interior epicycloid becomes a radial straight line, the inconveniences of which practice I have shewn †.

The following corollary is, I believe, new, and constitutes the basis of the system I propose to explain.

Corollary. If for a set of wheels of the same pitch, a constant describing circle be taken, and employed to trace those portions of the teeth which project beyond each pitch line by rolling on the exterior circumference, and those which lie within it by rolling on its interior circumference: then any two wheels of this set will work correctly together.

* Vide Hawkins's Notes to Camus, page 161.

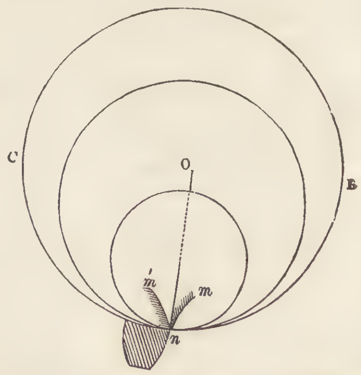
† Vide Brewster's Ferguson, Vol. II. p. 223. Camus, p. 27, or 25 new edition.

For, in the first place, it is well known and can be shewn from general principles, that the portion of tooth *within* the pitch line of a driving wheel, works only with the portion that lies *beyond* the pitch line of its follower, and that its action is confined to the approach of the point of contact to the line of centres. After the point of contact of the teeth has passed that line, then the case is reversed, and the portion of the driving tooth which lies *beyond* the pitch line is in contact only with some part of the follower's tooth which lies *within* its pitch line.

Now as a constant describing circle is used for the whole set, it is clear that the proposition will apply to any pair of wheels both before and after the teeth have passed the line of centres, for in each case we have an exterior epicycloid working with an interior epicycloid, and both have been drawn by the same describing circle, that is, by the constant circle of the set.

To carry this scheme into practice, it only remains to settle the proper diameter to be given to this constant describing circle, which may be done by considering the effect this diameter has upon the form of the tooth.

Fig. 2.



Let B Cn, Fig. 2, be a pitch circle whose centre is O, then upon this system the flank of the tooth, or that portion which lies within the pitch circle, will be an arc of an interior epicycloid (or hypocycloid) $m'n$ or mn. Now if the describing circle be of half the diameter of the pitch line, the flank will become a straight line coinciding with the radius On. If the describing circle be of less than half the diameter of the pitch line, the flank $m n$ will be concave, and the base of the tooth will spread; but if the describing circle be of more than half the diameter, the flank $m'n$ will be convex, and the base of the tooth lessen inwards, a form manifestly unpractical and useless. Hence the describing circle must not be greater than half the diameter of the pitch line.

On the other hand, if the diameter be too small, the base of the tooth will spread inconveniently, and the curvature of the exterior epicycloids be injuriously increased, therefore, on these grounds, it should be made as large as it can consistently with the limitation just stated, so that we finally obtain this rule for finding the diameter of the constant describing circle for a set of wheels.

Make it equal to the radius of the least pitch circle of the set.

And as pinions should never have less than 12 or 14 teeth, it would be well to establish one of these numbers for that least pitch circle.

The proposition and corollary being perfectly general, will apply to racks, which must be considered as very large wheels, and also to annular or internal wheels. Accordingly, if the constant describing circle be employed in tracing their teeth, they will work correctly with any wheel of the set.

It will be seen that this system is more easy of practice for the workman than the old one. Every epicycloid requires two circular or rather segmental templets, which are usually cut out of thin board. One of these, which may be termed the pitch templet, has its edge formed into an arc of the pitch line of the wheel; the other, which represents the describing circle, and may be called the describing templet, has its circular edge formed accordingly. The tracing point is fixed upon the circumference of the latter, and the workman having previously described an arc of the pitch circle of the wheel upon his drawing board, fixes the pitch templet, so that its edge may coincide with this arc, and then causing the describing templet to roll upon the pitch templet, he traces the arc of the required epicycloid.

Now on the old system, a set of wheels requires as many templets as there are pitch circles in the set, and also as many describing templets, but on the system just explained, only one describing templet is needed. As, however, the flanks of the teeth within the pitch circles become curves instead of straight lines, it is necessary to have concave templets adapted to the pitch circles, upon whose edges the describing templet may be made to roll for the purpose of obtaining the proper interior epicycloid. The best way is to make each pitch templet with two edges, one convex and the other concave, as in the figure, and to write the diameter upon each of them.

ON A FORM OF INCREASED STRENGTH.

In a large class of machinery, the wheels constantly move in the same direction, and whenever this is the case, it is possible to increase the strength of the teeth in a very great degree, by an alteration of the common form represented in Figure 3, Plate IX.

Let A B, C D, be the acting faces of the teeth of a pair of wheels, of which

MN, RS, are parts of the pitch lines. Now, according to the ordinary practice, the backs of the teeth would be formed exactly in the same manner as the acting faces, as shewn by the dotted lines, and this enables the teeth to work backwards or forwards at pleasure if required. If, however, the back is never required to act, the strength of the tooth will be nearly doubled by making it of the form B*egK*, that is, by taking off the portion B*me*, and filling up the nook *eng*. Teeth so formed will clear each other quite as well as those formed in the usual manner, with the advantage of a root of nearly double extent, and as the acting faces remain of the usual form, they will work together just as the ordinary teeth do. Strictly speaking, the back B*eg* should be an arc of an involute so proportioned as to work correctly with the corresponding back of the tooth of the other wheel. For then, as the backs of the teeth would drive each other truly, they are sure to clear each other; and besides, if the machinery be made accidentally to run backwards, the teeth will still work, although with a considerable divergent pressure upon the axes *. It will be quite near enough, however, to make the back an arc of a circle described through the points B*eg*, the first of which, B, should be taken a little way from the point of the tooth in order to blunt it slightly; the second, *e*, on the pitch circle is set off in the usual manner, so that T*e* may be about $\frac{5}{11}$ths of the pitch; and the third point, *g*, may be found by dividing AK into five parts, and taking *g*K equal to one of them. The space *g*K is required to enable the point of the corresponding tooth to clear itself.

This form resembles the saw shaped teeth which have been employed occasionally by mechanists, for example, (according to Mr. Reid, in his Horology, p. 100,) Lepine, of Paris, had in some of his watches the teeth and pinion-leaves of a saw teeth form, but I am not aware that the advantage of this shape has ever been systematically shewn, or any principle of its formation given.

* This divergent pressure will do no harm, because the kind of machinery to which I propose to adapt this form, never drives backwards, while the working pressure is upon it, but only during some previous adjustments, when the only pressure to be overcome is that produced by inertia or by the friction of the parts of the engine upon each other.

SECTION II. ON A PRACTICAL APPROXIMATION TO THE TRUE FORM BY ARCS OF CIRCLES.

Although the practice in the best workshops is to describe the shape of a tooth carefully with templets in the manner just described, yet this is not done for every tooth in the wheel or pattern; on the contrary, having traced the shape of a single tooth in this manner, the workman next finds with his compasses, by trial, a centre and small radius by which an arc of a circle can be described that will coincide as nearly as he can manage to make it with the templet-traced epicycloid. Then having struck upon the face of the rough cogs a circle concentric with the pitch circle, and whose distance from it is equal to that of the centre of his arc, he adjusts his compasses to the small radius, and always keeping one point in the circle just described, he steps with the other to each cog in succession, they having been previously divided into equal parts corresponding to the pitch and breadth of the teeth. Upon each cog he describes two arcs, one to the right and the other to the left, which serve him as guides in shaping and finishing the acting faces.

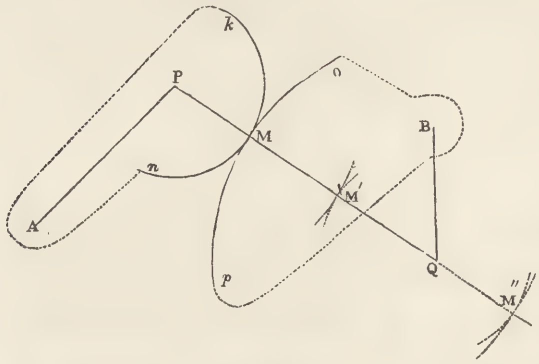
The portion of curve employed in a tooth is so short, that a circular arc would be quite sufficiently accurate, if its centre and radius were determined more correctly than by this coarse mode of trial. This consideration induced me to investigate the method I am about to describe, in which the examination of the nature and properties of the curves made use of for teeth is entirely dispensed with. I have deduced a simple construction by which a pair of centres may at once be assigned for a given pair of wheels, from whence, if arcs of circles be struck and employed for the working faces of teeth, they will answer the purpose of enabling these wheels to work correctly together *. I have

* Euler, in his second paper on the teeth of wheels, (N. C. Pet. XI. 209,) has with his usual ability investigated the proper curves, by examining the relation between their radii of curvature at every point. This method has naturally conducted him to results of a similar nature to those which I have given in the following pages, and he suggests that a small arc of the circle of curvature would suffice in practice for the forms of teeth. He has given some geometrical constructions for this purpose, and has then passed on finally to recommend the involute as the best curve, this paper being, in fact, the first in which that curve is pointed out as possessing the required properties. To Euler, then, belongs the merit of first suggesting the substitution of an arc of the circle of curvature for the real curve, a hint which has been, as far as I know, neglected by every succeeding writer. This may perhaps be attributed to the abstruse manner in which he has treated the subject.

also shewn the conditions under which this system may be made to acquire the essential property of enabling any two wheels of a set to work together, and finally, have endeavoured to present it in the best form for the workshop, by laying down tables and scales derived from it in the form of an instrument, which I have denominated an *Odontagraph*.

We must first examine the nature of the motion which is produced by the pressure of one circular arc upon another when disposed so as to work in the manner of teeth.

Fig. 4.

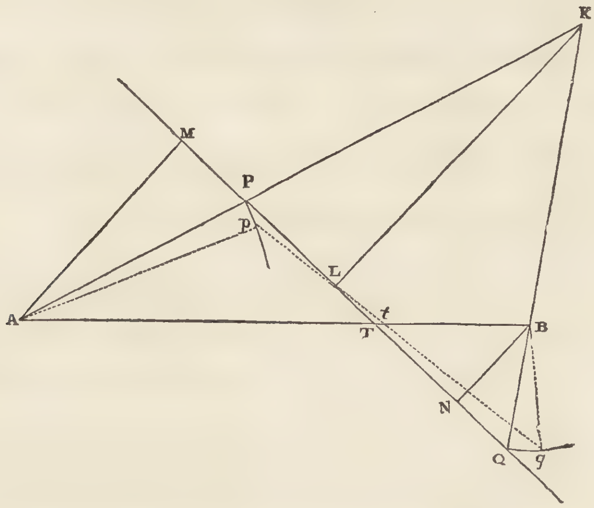


Let AB, fig. 4, be two centres of motion, kMn a piece formed into a circular arc described from a centre P, and capable of revolving round A; oMp in like manner a circular arc described from Q, and capable of revolving round B; now if the arc kMn be made to press against oMp, so as to communicate rotation to it round B, the line PQ joining the centres of the arc will necessarily always pass through the point of contact M, and will be of a constant length equal to the sum of the radii, so that in fact the motion will be exactly the same, if for the circular arcs a link PQ be substituted, which length is equal to the sum of the radii PM, QM, and which is jointed to the revolving pieces at P and Q, the places of the centres.

This also shews that a change of the actual lengths of the radii PM, QM, will not affect the motion, so long as the distance of the centres is constant, for that whether the circular arcs had been struck through M or M′, or even through a point M″ beyond the centre Q, the system would still have been equivalent to the link PQ, jointed to the arms AP, BQ.

It is only necessary then to examine the motion of this simple system of rods, and then to explain how it may be employed in forming the teeth of wheels.

Fig. 5.



Let the rod AP, Fig. 5, be moved into a new position Ap, its extremity will carry with it the end of the link PQ, and communicate through it a motion to the arm BQ, by which it will be driven into the new position Bq; and it is necessary to know the relative value of this motion to that of AP, which produced it.

Now this relation is continually changing, but its value at any instant may be thus determined. The rod PQ during its motion may be considered as always turning round some centre or other in space, although the relative position of that centre to it is continually shifting. Produce the arms AP, BQ in the requisite directions to meet in K, then will this point K be the momentary centre. For as the extremity P moves round the centre A, the direction of its motion at starting from P must be perpendicular to AP, therefore the momentary centre will lie somewhere in AP produced. In like manner the initial motion of the other extremity Q must be perpendicular to BQ, and the momentary centre must also lie somewhere in the direction of BQ; therefore it must be in the intersection K of the two lines AP and BQ produced. But since the rod PQ turns on the momentary centre K, the direct motion of P and Q are to each other at any given instant as their radial distances from K, that is, as PK to QK, which is true, whether we consider them as the extremities of the rod PQ or of the radii AP, BQ; also the angular motions of the latter will be found by dividing these direct motions by their respective radii; therefore we have,

Angular motion of P round A : angular motion of Q round B $:: \frac{PK}{AP} : \frac{QK}{BQ}$.

Draw KL, AM, BN, perpendicular to PQ. Then we have

$$
\begin{array}{lll}
PK : AP :: KL : AM & \text{by similar triangles} & KPL ; APM \\
BQ : QK :: BN : KL & \ldots\ldots & BQN ; KLQ \\
AT : BT :: AM : BN & \ldots\ldots & ATM ; TBN
\end{array}
$$

and compounding these three proportions we obtain

$$\frac{PK}{AP} : \frac{QK}{BQ} :: BT : AT$$

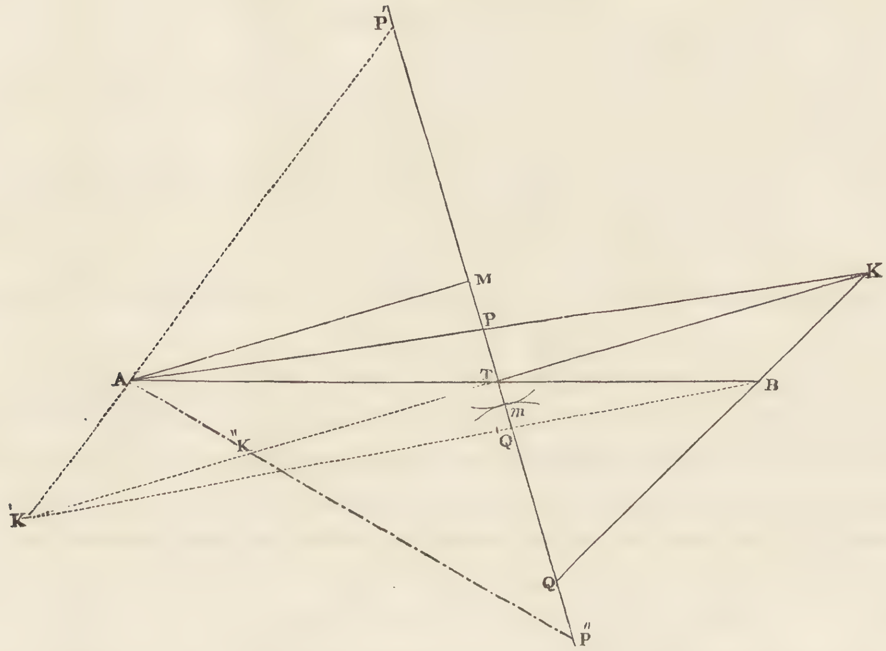
that is to say, the angular motion of the arms are to each other at any moment inversely as the segments into which the direction of the link divides the line joining the centres of motion, or *line of centres,* as it is usually termed. If now it happens that when the link PQ moves into its new position pq, very near to the first, this second position intersects the first in a point L above (or below) the line of centres, as in the figure; then the ratio of the segments AT, BT will be altered into that of At, Bt, consequently the ratio of the angular motion will be an increasing or decreasing ratio, as the case may be. But if the point L coincide with the line of centres, this ratio will for the moment remain constant.

Now a little consideration will show that the point of intersection between two successive positions PQ, pq of the link must be at the place where the perpendicular from K falls upon it. For as K is the momentary centre of motion of this link, the extremity L of the perpendicular will begin to move in a line at right angles with it, and consequently will remain in the direction of the first position PQ when the link has passed into the second pq, that is to say, it will be the point of intersection of the two positions; when, therefore, the rods are in such a position that the perpendicular from K meets the link PQ in the line of centres, the ratio of the angular motions of AP and BQ is constant: and if in this state of the system the points P and Q be employed (as in Fig. 4) as centres from whence short arcs are drawn through any common point M, and applied as teeth, these arcs will manifestly drive each other correctly when in the exact relative position described, and very nearly so when removed to a short distance on each side of it, which is the thing required *.

* It is hardly necessary to remark, that a more direct and simple demonstration of this construction might have been given by employing infinitesimals, which I was desirous of avoiding in a practical paper.

Now these relative positions of P and Q may be determined by a simple construction founded upon the necessary coincidence of L with T.

Fig. 6.



Let A and B, Fig. 6, be the given centres of motion, AB the line of centres divided in T, so that the segments AT, BT shall have the ratio of the required motions; or in other words, let T be the point of contact of the pitch lines. Draw PTQ, making any angle with AB, and through T draw TK perpendicular to it. Upon PTQ assume a point P as a centre, from whence the circular arc or tooth belonging to A is to be drawn. Then, to find the corresponding centre for B, join AP, and produce it to meet TK in K, join KB, and produce it to meet PTQ in Q. Then will Q be the point required, which will appear by comparing this diagram with Fig. 5.

If the point P had been taken at P′, so that the angle AP′T were less than a right angle, then the line P′A would have intersected TK in a point K′ on the other side of T, and this would have thrown Q to Q′ nearer to T.

Again, P might have been assumed on the other side of AB as at P″, but then the driving arc struck through *m* would have been concave. It is not worth while to examine all the cases that arise from the different relative

positions of the points; I shall merely show those that are applicable to practice.

The side of the tooth may be formed either of a single arc or of two. As the arc is only an approximation, and is, strictly speaking, only exact at one point of the action, it will be better to adopt a figure composed of two arcs of circles, as we obtain two exact points; but in that case one arc should be concave and the other convex, in order to facilitate their junction and produce a wider base; and thus a figure is formed, as we shall see, very near to that usually adopted, the convex arc being of course given to that part which lies outside the pitch circle, and the concave to that which extends within it.

The angle ATP is arbitrary, and its value may therefore be determined from other conditions than those already stated. If, however, it be made a right angle, it is clear that the points P and Q vanish by coinciding with T; and if it be made a little less than a right angle, the points P and Q are thrown so near to T that the radii by which the arcs are struck become too short, and the points of the teeth too much rounded off.

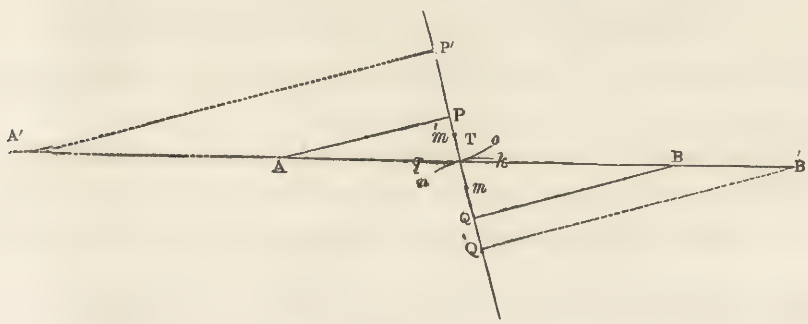
On the other hand, if the angle ATP is made too acute, the action of the teeth upon each other at the moment of passing the line of centres and elsewhere becomes very oblique, and an injurious pressure is thereby thrown upon their axes. By various trials I have fixed upon 75° as the value of the angle which appears to avoid these two extremes, and have accordingly employed it in the construction of the Odontagraph.

Again, the position of the point *m*, through which the arcs are to be struck, is also arbitrary, and must be determined by considering which point of the action we wish to make the correct point. If the teeth consist of a single arc each, the correct point may be fixed at the moment of passing the line of centres, and therefore the arcs must be struck through the point T; but if the side of the tooth be formed of two arcs joined, one lying within, the other beyond the pitch line, then the action of one of them will be confined to the approach of the point of contact of the teeth to the line of centres, and the action of the other to its recess from that line, and *m* must be assumed upon such a principle that the correct point of each arc shall fall nearly in the middle of its action, the mode of doing which will appear presently.

TO DESCRIBE TEETH CONSISTING OF A SINGLE ARC.

If the side of the tooth consist of a single arc, the system may be made exceedingly simple, for as the distance of the point K from T is arbitrary when the points P or Q are not given, suppose it to be taken at an infinite distance, then (Fig. 6) A P K and Q B K will become parallel to T K, and perpendicular to P T Q, which shews that if lines be drawn from A and B (Fig. 7) perpendicular to P T Q, the points P and Q will be centres, whence if arcs be drawn through some common point m, or rather in this case T, these arcs will drive each other correctly.

Fig. 7.



If the angle P T A remain constant for a set of wheels of this kind, any two of them will work truly together, provided the arcs be struck through the point T; for let the wheel, whose radius is A T, be removed, and another whose radius is A′ T be substituted, A′ P′ drawn perpendicular to T P P′ will give the point P′ as the centre belonging to the arc $o\,q$, and it is clear that this new arc $o\,q$ will work as well with $k\,n$ as the former one, and also that if the radius A′ T had been substituted for B T instead of for A T, by placing it and its corresponding line A′P′ in the situation indicated by the dotted lines B′Q′, that still the conditions of the construction would have been satisfied, and these two wheels worked truly together, and the same may be shewn of any other pair of radii. But if the arcs were struck through a point m, not coinciding with T, then the wheels would fall into two groups, in one of which, as A T, A′T, the arcs are struck through a point m on the opposite side of the line of centres to the centre points P, P′, and in the other, as B T, B′T, they are struck through a point m on the same side of the line of centres as the

centre points QQ′. Any wheel out of one of these groups will work correctly with any wheel taken from the other.

But suppose that a pair of wheels out of one of these groups be put together, for example, out of that in which the point *m* and the center point of the arc, lie on opposite sides of the line of centres, and let AT and BT be the radii of the wheels in question. Now the relative positions of the points P and Q will still be true, but the arcs will no longer be struck through a common point, one of them being through *m*, the other through *m′* at the same distance on the opposite side of T, and therefore they will not work truly together. The arcs of the entire set must therefore be struck through T, and then any two wheels of the set will work.

The distance TP is equal to AT × cos ATP, and if ATP be fixed at 75°, which is a convenient value, then TP = ·2588 × AP, whence the value is very easily found for any given radius, for in this case the value depends upon the radius alone and not on the pitch or number of teeth, as in the next example. The practical mode of setting out the teeth is shewn in Fig. 8, Plate IX. Make a bevel, as in the figure, whose angle at T shall be 75°, and graduate its edge into a scale of inches and tenths, bearing to real inches and tenths the proportion of ·2588 to 1. Let A be the centre of a proposed wheel, BTC a portion of its pitch circle. Draw a radius AT, and apply the bevel as in the figure, with its angular point T upon the pitch circle and its plain edge in coincidence with the radius. Read off the length of the radius in inches (which in this case is four inches) upon the graduated scale, and the point P so indicated on the drawing board, is the centre whence with a radius PT the arc *o*T*q* of the tooth is to be struck.

On this system, however, the tooth has but one true point, that is to say, it is only strictly exact at the moment of passing the line of centres, and I therefore greatly prefer the construction about to be described, in which the side of the tooth is made up of two arcs united, and consequently has two points of accuracy. The tooth just described has considerable analogy to the involute, and like it has the fault of acting with too great a degree of obliquity. The teeth next to be described are of nearly the same form as that which has been so long in use, and have, as well as those of Fig. 8, the property of allowing any pair of wheels in a set to work together.

TO DESCRIBE TEETH CONSISTING OF TWO ARCS OF CIRCLES.

Figures 9 and 10, Plate IX., represent a pair of so constituted teeth in contact, Fig. 9 shewing their action before they reach the line of centres, and Fig. 10 after they have passed that line; each tooth is formed of two arcs of circles, *ab*, *bc*, *de*, *ef*, of which the concave ones, *ab*, *ef*, are situated within the pitch circles, and the convex ones *bc*, *de*, extend beyond these circles; therefore, from well known principles, the concave arc *ab* will drive the convex arc *de*, until the point of contact reaches the line of centres, and then the convex arc *bc* will begin to drive the concave arc *ef*.

There are two points in the action of these teeth at which perfect accuracy is attained; one of them is when the teeth are in the position of Fig. 9, during the mutual action of *ab* and *de*, and the other when they are in the position of Fig. 10, during the action of *bc* and *ef*; and the arcs are so set out that these points of the action shall take place, the one nearly in the middle of the arc of motion before the line of centres is reached, and the other somewhere about the middle of the arc of motion that is traversed from the line of centres until the teeth quit contact.

The construction of these teeth in a set is as follows. AB, Figures 9 and 10, is the general direction of the line of centres; QPT, as before, is a line making a constant angle of 75° with the line of centres; KTK perpendicular to QPT and having its two points K set off at equal distances on each side of T, these points and the lines being invariable for the entire set.

The centres for the convex arcs are found by joining the centre of each wheel (A, Fig. 10; B, Fig. 9) with that point K which lies on the *opposite* side of the line QPT. Thus in Fig. 9, Q is the centre of the convex arc *de*, found by joining BK, and in Fig. 10, P is the centre of the convex arc *bc*, found by joining AK.

The centres for the concave arcs are found by joining the centre of each wheel with the K which lies *between it* and the line QPT; thus in Fig. 9, P is the centre of the concave arc *ab*, found by joining AK, and producing it to meet PQT, and in Fig. 10, Q is the centre of the concave arc *ef*, found by joining BK, and producing it to meet TPQ. Moreover, the whole of these concave and convex arcs are struck through a point lying beyond T at a constant distance, T*n*, or T*m*, which for simplicity's sake I have assumed equal to

half the pitch; finding that this will place the correct points of the action at a sufficient distance on each side of the line of centres.

The consequences of this arrangement will be that any pair of teeth so described will, when put together, answer the conditions of the construction already demonstrated. (Fig. 6.)

1st. (Figure 9.) Before reaching the line of centres we have a concave arc *ab* driving a convex one *de*, of which the first has been struck from a centre P, derived from its nearest K, and the second from a centre Q, derived from its farthest K, consequently both derived from the same K; also the arcs have both been struck through a point *m*, at the same distance beyond T, and therefore will work truly together.

2d. (Figure 10.) After passing the line of centres, a convex arc *bc* drives a concave arc *ef*, which in like manner are seen to have been derived from the same K, and to have been struck through a common point *n*, so that although the position of all these points is reversed, the arcs will, in this case, work truly together.

The same will manifestly be true for every pair of wheels in the set, for the distances TK and T*m*, or T*n*, are constant for the whole.

DESCRIPTION OF THE ODONTAGRAPH.

To enable a workman to find these points P and Q at once in every case, I have contrived the instrument which I have termed an Odontagraph, and which is represented in Figure 11, Plate IX., with the arrangements for describing the tooth *fed* of Figures 9 and 10. These three drawings being all made to the same scale will explain each other by comparison.

The instrument consists of a kind of bevel formed of a sheet of card paper, four times the lineal size of the drawing EFT′D, the angle DT′*k* is 75°, and the side *k*T′F is occupied by a scale of equal parts numbered from T′ both ways *. The plain surface of the card is principally occupied by the pair of Tables given in the next page, and by directions for their use.

* The divisions in the engraving are made proportionally larger than in the real instrument for the sake of clearness. The actual scale to which the Tables are adapted is divided into half inches, which are subdivided into tens and numbered from T′ both ways, the one from 0 to 210, and the other from 0 to 40.

Let the example be a wheel of 26 teeth 2 inch pitch. Describe an arc T′*e*T of the required pitch circle, and set off upon it T′T equal to the pitch and bisected in *e*, draw radial lines BT′, BT. To describe the arc *ef* within the pitch circle, apply the slant edge DT of the scale to the upper radial line BT′, placing its extremity T′ on the pitch circle, as in the figure. In the Table headed "centres for teeth within the pitch circle," look down the column of 2 inch pitch and opposite to 26 teeth will be found the number 37. The point indicated on the drawing board by the position of this number at Q on the scale of equal parts T′F, which is marked *Scale of centres for teeth within pitch circle*, in the actual instrument, is the centre required, from which the arc *fe* must be drawn with a radius Q*e*.

Now a comparison of this figure with Figure 10, will show that thus far the relative positions, inclinations and distances have been indicated by the instrument for the point Q′. (the Q of Fig. 10.) The line BT′, Fig. 11, is the same as BT in Fig. 10.

The centre for the arc *ed*, which lies outside the pitch circle, is found in a manner precisely similar, by applying the slant edge of the scale to the lower radial line BT, placing the instrument in the position indicated by the dotted lines. The Table of Centres for teeth outside the pitch circle does not contain 26 in its column of Number of Teeth, therefore the nearest number must be taken, which in this case is 30, and the number 14 opposite to it in the column of 2 inch pitch, will indicate the position of the centre Q upon the scale T*k* of *centres for teeth outside the pitch circle*, this scale being so titled in the actual instrument. Here, again, a comparison of Figure 11 with Figure 9, will shew that this new operation has given the true relative position of the point Q to the radial line BT and arc *de* *.

* The description given above will enable any one to form the instrument, but those who are not disposed to take that trouble may obtain it either of card-paper or metal from Messrs. Holtzapfel of Charing Cross.

Tables shewing the Place of the Centres upon the Scale.

CENTRES FOR TEETH WITHIN THE PITCH CIRCLE.

Pitch in Inches and Parts.

Number of Teeth.	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	3	$3\frac{1}{2}$
13	32	48	64	80	96	129	160	193	225	257	289	321	386	450
14	17	26	35	43	52	69	87	104	121	139	156	173	208	242
15	12	18	25	31	37	49	62	74	86	99	111	123	148	173
16	10	15	20	25	30	40	50	59	69	79	89	99	191	138
17	8	13	17	21	25	34	42	50	59	67	75	84	101	117
18	7	11	15	19	22	30	37	45	52	59	67	74	89	104
19	...	10	13	17	20	27	35	40	47	54	60	67	80	94
20	6	9	12	16	19	25	31	37	43	49	56	62	74	86
22	5	8	11	14	16	22	27	33	39	43	49	54	65	76
24	...	7	10	12	15	20	25	30	35	40	45	49	59	69
26	...	...	9	11	14	18	23	27	32	37	41	46	55	64
28	4	6	...	...	13	...	22	26	30	35	40	43	52	60
30	...	...	8	10	12	17	21	25	29	33	37	41	49	58
35	...	...	...	9	11	16	19	23	26	30	34	38	45	53
40	...	5	7	...	...	15	18	21	25	28	32	35	42	49
60	3	...	6	8	9	13	15	19	22	25	28	31	37	43
80	...	4	...	7	...	12	...	17	20	23	26	29	35	41
100	...	...	...	...	8	11	14	...	...	22	25	28	34	39
150	...	..	5	...	...	...	13	16	19	21	24	27	32	38
Rack.	2	...	...	6	7	10	12	15	17	20	22	25	30	34

CENTRES FOR TEETH OUTSIDE THE PITCH CIRCLE.

Pitch in Inches and Parts.

Number of Teeth.	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	3	$3\frac{1}{2}$
12	1	2	2	3	4	5	6	7	9	10	11	12	15	17
15	...	...	3	...	...	...	7	8	10	11	12	14	17	19
20	2	...	...	4	5	6	8	9	11	12	14	15	18	21
30	...	3	4	...	...	7	9	10	12	14	16	18	21	25
40	...	...	...	...	6	8	...	11	13	15	17	19	23	26
60	...	...	...	5	...	...	10	12	14	16	18	20	25	29
80	...	...	...	...	...	9	11	13	15	17	19	21	26	30
100	...	...	...	...	7	...	...	...	...	18	20	22	...	31
150	...	...	5	6	...	...	...	14	16	19	21	23	27	32
Rack.	...	4	...	...	...	10	12	15	17	20	22	25	30	34

It can be shewn that the curve *def* is also true for an annular wheel of the same number of teeth, *f* becoming of course the point of the tooth and *d* its root.

For a ***Rack*** the pitch line TT′ becomes a straight line, and BT′, BT will be

drawn perpendicular to it at a distance $TT_{\prime}$ equal to the pitch and the instrument applied as before.

A number of 12 teeth is not inserted in the Table of Centres for teeth within the pitch circle, for in that case, the part which lies within the pitch circle is a portion of a radius tending to the centre of the wheel.

If pitches are required intermediate to those in the tables for centres, the column belonging to the nearest pitch may be employed without a serious error, or a number may be taken halfway between those given in the two several columns. More accurately the numbers may be deduced from those of some other column by direct proportion; thus, numbers for 4 inch pitch, may be obtained by doubling those in the column of 2 inch pitch.

When the proper centre and radius have been obtained from the Odontagraph for a single tooth, they may be employed in the usual manner described at the beginning of this section.

I will now explain in a few words the mode of calculating the numbers in the table, by way of enabling other persons to alter any of the conditions. A formula for these numbers may be obtained as follows. (Vide Fig. 6.) From A draw AM perpendicular to TPP′, then from the similar triangles AMP, PTK we obtain $KT = \frac{PT \times AM}{PM} = \frac{PT \times AM}{TM - PT}$. Let $KT = C$, $AT = R$, $PT = D$, $ATP = \theta$;

$$\therefore \quad C = \frac{D.R.\sin\theta}{R.\cos\theta - D} \quad . \; . \; . \; . \; (1)$$

Now the point P being in this case obtained from the K on the opposite side of T to A, this formula belongs to that part of the tooth which lies beyond the pitch circle, according to the principles already laid down. If TK″ be taken equal to TK on the line KT produced, and a point P″ obtained by joining AK″, and producing the line to meet P″PT, then P″ will belong to the part of the tooth within the pitch circle, and the similar triangles AMP″, P″TK″, will give us for this case the formula

$$C = \frac{D'R\sin\theta}{R\cos\theta + D'} \quad . \; . \; . \; . \; (2); \text{ where } D' = TP''.$$

Now the value of C, which represents the equal lines KT, or K″T, may be determined for the whole set, by considerations similar to those already employed in settling the diameter of the constant describing circle in the first section of this paper. If the radius AT of a wheel be assumed of such a length

that AK″ fall perpendicularly upon K″T, then will the line AK″P″ become parallel to PTP″, and consequently the point P″ will go off to infinity, and the arc which should be struck from it to form the flank of the tooth will become a right line perpendicular to PTP″.

If the radius AT be taken still smaller with respect to K″T, it will be seen (by taking K′T larger than AT) that in such a case the point P, will make its appearance on the opposite side of T *, but this makes the flank of the tooth convex, and drawing inwards so as to be less at the base than at the pitch line, which is an impracticable form. To avoid this, and at the same time to make K″T as large as possible consistently with this limitation, assume K″T equal to $R' \sin\theta$, where R′ is the least radius of the set. This value corresponds to the case in which AK″ is perpendicular to K″T, and necessarily excludes the impracticable forms; for since the least radius of the set now corresponds to that peculiar example in which AK″P″ is parallel to PTP″, every other value of AT being larger, will throw the points P″ on the opposite side of T to M, which is the thing required to produce the concave flank. These observations apply only to that value of KT which lies nearest the centre A, and therefore to the flank or portion of tooth within the pitch circle. As to the opposite value of TK, which corresponds to the portion of tooth beyond the pitch circle, and which it must be remembered is equal to TK″, it is clear from the figure that whatever value be given to it, its point P will always lie between T and M, and the arc of tooth be convex, supposing it to be struck, as it must be, through a point near to T.

The value selected for K″T (namely $R' \sin\theta$) will therefore suit KT. Substitute now this value for C in the formulæ (1) and (2), and after arranging the terms we obtain the following values of D and D′.

$$D=\frac{R'R\cos\theta}{R+R'} \cdot \cdot \cdot \cdot \cdot (3) \qquad \text{and } D'=\frac{R'R\cos\theta}{R-R'} \cdot \cdot \cdot \cdot \cdot (4)$$

Now D and D′ (that is TP and TP″) are the distances of the centre points of the arcs measured from T, and it will be seen by comparing the diagrams with the description of the Odontagraph, that the numbers in the columns of each pitch are the values of D and D′, corresponding to the number of teeth in each wheel given in the first column, or, which is the same thing, to the values of the radii R and R′. To find these numbers for a given pitch,

* Our formula then becomes $C=\frac{D'R\sin\theta}{D'-R\cos\theta}$.

substitute in (3) and (4) the particular values of R' and θ, and by help of a table of logarithms, the values of D and D′ belonging to as many values of R as may be thought necessary, may be computed, and thus the column of numbers obtained for that pitch. Those of the other pitches may be derived from the first by common proportion. In this way I formed the table, assuming 12 for the least number of teeth, and 75° for the value of θ, and employing a scale of half inches and tenths in which to express the values of D in the nearest whole numbers, because I found that a unit of the twentieth of an inch was sufficiently small to avoid practical error.

It is unnecessary to have numbers corresponding to every wheel, for the error produced by taking those which belong to the nearest as directed, is so small as to be unappreciable in practice. I have calculated the amount and nature of these errors by way of obtaining a principle for the number and arrangement of the wheels selected. It is unnecessary to go at length into these calculations which result from very simple considerations, but I will briefly state the results.

The difference of form between the tooth of one wheel and of another is due to two causes, (1) the difference of curvature, which is provided for in the Odontagraph by placing the compasses at the different points of the scale of equal parts, (2) the variation of the angle T′BT, (Fig. 11,) which is met by placing the instrument upon the two radii in succession.

The first cause is the only one with which these calculations are concerned. Now in three inch pitch the greatest difference of form produced by mere curvature in the portion of tooth which lies beyond the pitch circle, is only ·04 inch between the extreme cases of a pinion of twelve and a rack, and in the acting part of the arc within the pitch circle is ·1 inch, so that as all the other forms lie between these, it is clear that if we select only four or five examples for the outer side of the tooth and ten or twelve for the inner side, that we can never incur an error of more than the $\frac{1}{200}$th of an inch in three inch pitch by always taking the nearest number in the manner directed, and a proportionably smaller error in smaller pitches. But to ensure this, the selected numbers should be so taken, that their respective forms shall lie between the extremes at equal distances. Now it appears that the variation of form is much greater among the teeth of small numbers than among the larger ones, and that in fact the numbers in the two following series are so arranged that the curves corresponding to them possess this required property.

For the outer side of the tooth, 12, 14, 17, 21, 26, 34, 47, 73, 148, Rack.

For the inner side, 12, 13, 14, 15, 16, 17, 19, 22, 26, 33, 46, 87, Rack.

Now these numbers, although strictly correct, would be very inconvenient and uncouth in practice if employed for a table like that in question, where convenience manifestly requires that the numbers, if not continuous, should always proceed either by twos or fives, or by whole tens, and so on. They are only given as guides in the selection, and by comparing them with the actual table, their use in the formation of the first column will be evident.

ON TEETH WORKING WITH TRUNDLES OR RADIAL FLANKS.

The particular applications of the general construction which I have given, apply only to complete sets of wheels working together, and it may be as well to shew its use in obtaining teeth adapted to work with trundles or pin wheels, as well as teeth in which the flank is a radial line as in the common form. The diagram of Fig. 12, Plate IX., must be drawn of the full size for any required wheel, A and B are the centres as usual, fg and hk arcs of the pitch circles. Upon the radius of the trundle AT describe a semicircle, upon which set off from T, TP equal to the pitch. Draw PTQ and let fall a perpendicular BQ upon it from B, intersecting it in Q. If the point P be taken for the centre of the stave or pin, an arc mn described from Q and touching the stave in m, will be the side of the tooth required.

If the flanks of the teeth are to be radial lines, then the portions lying without the pitch circle may be arcs of circles found thus. (Fig. 14.) A and B are the centers; fg, hk, arcs of the pitch circles as before. Upon AT describe an entire circle, and upon its circumference from A and T set off Az, Tm equal to each other and to about three quarters of the pitch; join Bz and through mT draw mTQ intersecting Bz in Q; then an arc described from centre Q and struck through m, will be the curved face of the tooth for BT, and this will work with the radial flank of the tooth of AT. To find the curved face of the latter tooth make a similar diagram, in which AT and BT exchange places.

ON CUTTERS.

The Odontagraph is also applicable to the obtaining a correct form for the cutters used in shaping the teeth of metal wheels. The form of the cutter is that of the space between two teeth, and in order to shew the nature of the change of form required for different teeth as well as the general form itself, I have in

Figure 13, Plate IX., drawn with accuracy, and on a large scale, the teeth proper to the two extreme cases of a pinion of 12 on the one hand, and a rack on the other, and have applied these two together, so that the central line of the spaces shall coincide, and thus bring the shapes of the cutters into direct comparison.

Now between these two lie all the forms that are required for any number of teeth from 12 to a rack, or the largest possible wheel; but in making a set of cutters, for small pitches especially, it is by no means necessary to make one for every number, as the forms for numbers that lie close together are so nearly alike that the errors of workmanship would entirely destroy the difference.

The variation of form however is much less among high numbers than in low ones. For example, the difference of form between a cutter for 150 teeth, and one for 300, is not greater than that between cutters for 16 and 17 teeth.

This being the case, it appeared worth while to investigate some rule by which the necessary cutters could be determined for a set of wheels, so as to incur the least possible chance of error. To this effect I have calculated, by a method sufficiently accurate for the purpose, the following series of what may be termed equidistant values of cutters; that is, a table of cutters so arranged, that the same difference of form exists between any two consecutive numbers.

Table of Equidistant Values for Cutters.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
No. of Teeth.	Rack.	300	150	100	76	60	50	43	38	34	30	27	25	23	21	20	19	17	16	×	15	14	13	×	12

This will be a guide in the selection of the wheel to which each cutter shall be accurately adapted after it has been determined how many are necessary in a set. For example, if a single cutter were thought sufficient for very small wheels, it had better be accurately adapted to teeth of 25, for that value is intermediate between the two extremes. If three cutters are to suffice for the whole set, then 76, 25, and 15 must be selected, of which the cutter 76 may be used for all teeth from a rack to 38, the cutter 25 from 38 to 19, and the cutter 15 from 19 to 12, and so on.

It appears from the figure that the greatest difference of form is at the apex of the tooth, (that is, at the base of the cutter,) and amounts to ·25 inch in 2 inch pitch; from this the difference may be ascertained for any smaller pitch, and as many cutters interposed as the workman's notion of his own powers of accuracy may induce him to think necessary.

Thus if the hundredth of an inch be his limit of accuracy in forming cutters, and he is making a set for half inch pitch, where the difference of form is $\frac{1}{4} \times {\cdot}25$ or ·06 nearly, then half a dozen cutters will be sufficient, and these must be made as nearly as possible to suit the wheels of 150, 50, 30, 21, 16, 13.

The following table contains a selection of numbers for different cases, which may save trouble.

Table of Cutters.

No. of Cutters in the set.	Numbers of Teeth to be selected.																							
2	50	16																						
3	75	25	15																					
4	100	34	20	14																				
6	150	50	30	21	16	13																		
8	200	67	40	29	22	18	15	13																
10	200	77	50	35	27	22	19	16	14	13														
12	300	100	60	43	34	27	23	20	17	15	14	13												
18	300	150	100	70	50	40	35	30	26	24	22	20	18	16	15	14	13	12						
24	Rack.	300	150	100	75	60	50	43	38	34	30	27	25	23	21	20	19	18	17	16	15	14	13	12

When the numbers have been selected, the Odontagraph may be employed to draw the figure of the cutter corresponding to each wheel, either on the same scale as the proposed cutter, or on a much larger scale, which may be afterwards reduced proportionally.

ROBERT WILLIS.

XI.—*A series of Experiments on the strength of Cast Iron.* By FRANCIS BRAMAH, *M.Inst.C.E.*

A CONTRARIETY of opinions amongst scientific men as to the principles on which the strength of cast iron beams to resist stress and flexure ought to be estimated, induced me, in the year 1834, to institute a course of experiments to verify the principles assumed by Tredgold in his Treatise on Cast Iron—a work which has contributed so much to establish the practical value of that material for the many important purposes in buildings and machinery to which it has been applied *. This difference of opinion has originated principally from the known fact, that the ultimate resistance to compression considerably exceeds that to extension. It is the custom of many, even at this period of our advancement in science, to determine the value of material to resist stress and flexure by its resistance to fracture, thus regarding only the obvious testimony of those effects which in practice they are too anxious to avoid, without ever contemplating or reasoning upon the invisible effects which we are sure must be taking place, but of which no evidence is afforded externally.

One principle upon which the law of resistance is founded, viz., "*ut tensio, sic vis*," can only be applied within the limit of the elastic power of the material; beyond this limit it no longer obtains; the effect following no fixed ratio, but increasing very irregularly toward the point of fracture.

That the extent of the elastic power of the material is the limit of practical strength there can be no doubt, for as soon as the applied force exceeds that amount, the tenacity of the material becomes sensibly impaired, and the injury increases rapidly as the point of fracture is approached. The coincidence of the two forces, extension and compression, to produce equal effects when confined within the limit of elasticity is very striking, and their divergency after passing that point is equally remarkable.

The following experiments were principally directed to this point without reference to the comparative results of the various sections, although from the simi-

* I am deeply indebted to my valued friend, and at that time my principal assistant, Mr. A. H. Renton, for his superintendence of the experiments, and for the "Observations on the Experiments" embodied in this communication.

larity in the quality of the material they will furnish a very close and probably a more decided approximation than practice usually presents.

The beams were subjected to the pressures by means of weights applied in a scale attached to the extremity of a long lever, exactly counterbalanced. (See Plate X.) Mechanical advantage 12 to 1, so that by additions of 4 lbs. in the scale, 48 lbs. pressure was exerted on every application. Hence, in order to ascertain the actual load on the various specimens, the tabulated number of pounds which was suspended from the lever of the testing machine must be multiplied by 12.

There were two similar specimens of the beams of each section, except in Experiment VII., the only difference between which is an opening that was left in the upper rail in No. 13, into which a loose piece of steel was inserted; the difference of actual strength between the two appears to be very slight, as will be seen by reference to the Tables of Experiments. In consequence of the index being deranged, the results for one specimen only in the experiment on the simple rectangular section have been recorded.

The experiments are tabulated in the order in which they were made, and the deflections given are such as were taken at the time, without any subsequent correction: and they are illustrated with corresponding sections, to facilitate by an easy reference the inspection of the results.

In each case there are three distinct columns, namely, one of applied weights, one of observed deflections, and one of differences. Considering the minuteness of the observed amount of deflection, the discrepancies which some of the columns for the two similar species exhibit are very trifling, and from the regularity which both precedes and succeeds them, where they do occur, there can be no doubt but that they arise either from error in observation or the friction of the machine, or from some minute irregularity which the delicacy of the index rendered sensible.

The observed permanent set in each specimen is marked with an asterisk in the column of deflections.

Nearly all the specimens tried were ultimately broken, shewing accurately the relative value of the sections at the point of fracture as nearly as the different quality of casting admits of, and also the approximation of the results within the elastic limit, the discrepancies amounting to a less quantity than the difference between the results of similar sections and cases. The identity of resistance to compression and extension, is clearly evident by a careful comparison of the different columns. For had the resistance been in the constant

ratio of the ultimate powers of the material, the same proportion would have obtained in every part of the scale.

In the illustrations of those specimens which were broken, the line of fracture is shewn by a dark line, and where the section of fracture was imperfect, from air bubbles or other causes, it has been tinted on the respective sections. (See Plates XI. and XII.)

As the fidelity of the result of an experiment depends much upon the means and the nature of the apparatus employed, the programme of the course of experiments is annexed, to shew the mode of operation and the care that was taken to insure accurate results.

PROGRAMME OF THE COURSE OF EXPERIMENTS.

Object.

As the object of these experiments is to shew the equality of the forces of extension and compression, and the comparative value of different sections to resist stress, when the load is confined within the range of the elastic power of the material, it is evident that any strain beyond that point would defeat the object in view ; it is therefore a principal feature in these experiments, and essential to the accuracy of the results, to note that point where the elastic power becomes impaired, and the specimens take a permanent set, and also to afford, by accurate observation, the means of comparing the deflections of each specimen under the same load; to further this end the following points require particular observation.

Correction for the apparatus.

The effect of the machine must be correctly ascertained; this will amount to the statical weight of the lever on the specimen, which will be a constant quantity; this should also include the scale suspended from the end, so that the weights may not be influenced by it; or, to adopt a more accurate mode of relieving the experiments from any inaccuracy resulting from the effect of the machinery, the lever may be balanced together with the scale, so as not at all to interfere with the results; the experiments may then commence from a much lower point.

Probable deflection.

The elastic power of the material will probably permit a deflection in the various specimens, as follows :

$$\text{Those of uniform depth} = \frac{\cdot 02\, l^2}{d}.^{*}$$

$$\text{Depth at ends } \tfrac{1}{2}\, d \qquad = \frac{\cdot 0327\, l^2}{d}$$

* See note, page 124.

These formulæ will serve as a guide to direct the observation to the desired point.

Readings.

The index being decimally divided may be read off to a 1000th part of an inch. To insure the nearest approach to practical accuracy, a silk thread to be used for the connection between the wood lever and the index barrel *.

General directions.

To prevent accidents to the indicating apparatus, two blocks must be used to limit the fall of the specimen should fracture take place.

The weights to be added in increments, which shall produce a deflection of about ·002 of an inch each, so as to give about thirty observations.

The sections and weights of the different specimens to be very accurately taken.

Order of trials. Plates XI. and XII.

The simple rectangular section to form the commencement of the series.

The specimens of uniform depth with the flange downwards.

Do., do., with flange upwards.

The specimens diminishing towards each end with the flange downwards.

Do., do., with the flange upwards.

The open beams with solid rail.

Do., do., with divided rail upwards.

The triangular beams with bases reversed.

The open flanged beams.

THE TESTING APPARATUS.

Plate X.

The bed of cast iron, A, was made of such a strength as to reduce the deflection of the machine to the smallest quantity possible, and fixed on two strong brackets, BB, well secured to the floor.

The lever C is connected to the bed by links, D, and is balanced upon V centres by counterweights and levers; it is shewn supported at two points in order to lessen the amount of weight on one particular point. The index plate consists of a disc 12 inches in diameter, divided into the equivalents for 1000th parts of an inch deflection, and these being of considerable magnitude, render it easy to read off to the 4000th part of an inch. The indication is transferred from the centre of the beam to the enlarged axis of the disc or dial by means of a

* This has since been replaced for subsequent experiments by a clock fusee chain.

lever 8 to 1; the diameter of the enlarged axis is 1·5 inches; a hole is drilled in the bed, through which a steel wire with an adjustable point passes, and rests upon the lever, which is of the second order, the adjusting point admitting of its adaptation to beams of any depth and irregularity by simply screwing it up or down as circumstances require; by this means the index can at any period of the experiment, if desired, be set to zero.

OBSERVATIONS ON THE EXPERIMENTS*.

A reference to the tables†, and a comparison of the value of various forms of section for cast iron beams within the elastic limit, will exhibit most clearly not only the accordance of Tredgold's theoretical deductions with actual experiment, but also the fallacy of the opinions sometimes entertained on the relation between the forces of compression and extension.

The tabulated results are here referred to in the same order in which they are there recorded.

Experiment I.—A beam of the simple rectangular section of uniform depth, the depth 3 inches, the breadth ·5 inches, and the bearing or distance between the points of support 3·083 feet. The load which produced a permanent set (as nearly as could be observed) was $104 \times 12 = 1248$ lbs., 1344 lbs. producing a set of ·005.

The load assigned by Tredgold in his Essay on Cast Iron, Art. 100, 2d Edit. as the limit of elasticity in iron of average quality is $\left(\frac{2fbd^2}{3l} = W = \right)$ 1240 lbs. The coincidence between the calculated and experimental results is very striking, and which has been uniformly found to obtain in beams of the largest scantling. The observed deflection with the above load was ·058 inch (the mean of two experiments gave ·059). Tredgold assigns ·063 inch as the deflection due to the elastic weight by his formula $\frac{\cdot 02\, l^2}{d}$ (Art. 174), a coincidence equally satisfactory; and when the probable difference in the quality of the metal of which the beams were made is taken into consideration, it may be regarded as a very close approximation. In this experiment the coefficient for a bar 1 inch square, 1 foot long, is 855 lbs.‡

Experiment II. Nos. 2 and 3.—These beams were of the single flanged kind,

* See note, page 113. † Pages 125–134. ‡ See note, page 124.

and were tested with the flanges downwards; that is, on the extended side of the beams. The depth was 3 inches and uniform, the same as in the last experiment; the breadth ·5 inch, the flange 1·5 inches wide, and ·5 inch thick. The weights of the two beams were different, owing to some trifling enlargement of the section in casting, and the lightest, No. 3, is selected for comparison with the next in order, No. 4, with which it nearly coincides in weight. The load producing permanent set was ($160 \times 12 =$) 1920 lbs., with a deflection of ·0655. The load assigned by Tredgold (Art. 856), is 1910 lbs. with a deflection of ·063. In No. 2, the deflection for a corresponding weight was ·075, owing to an air bubble in the section, as shewn in the figure. The set taking place at ($144 \times 12 =$) 1728 lbs. with a deflection of ·067, shewing the elasticity to be the same in both specimens. This approximation is sufficient to establish the most unlimited confidence in the ingenious mode of deducing the value of this section. In No. 2 the breaking weight is to the elastic weight as 434 : 144, or as 3 : 1. In No. 3, the coefficient for a bar 1 inch deep, 1 foot long, and of the same proportionate section, is 461·2 lbs.

Experiment III. Nos. 4 and 5.—No. 4 being nearly of equal weight with No. 3, last cited, will admit of comparison. Taking the same applied weight, we have the corresponding deflection ·0705, the difference may be owing to an air bubble in the section, which being only ·005, is too insignificant a quantity to be considered as a deviation from the law as laid down by Tredgold. In No. 4, the breaking weight is to the elastic limit as 378 : 160, or as 2·36 : 1. The coefficient for a beam 1 foot long and 1 inch deep, of a proportionate section to this specimen, is the same as No. 3, 461·2. It has been considered by many that the single flanged beam and all assimilations to it, as the triangle, &c., are stronger with the flange down than with the flange up; but it is clearly shewn by these and the succeeding experiments, that such opinions are not founded either upon the physical properties of matter, or upon any practical results obtained from direct experiments. It may, however, here be observed, that those opinions have most generally been formed upon experiments on the breaking weights.

Experiment IV. Nos. 6 and 7.—Were of similar section at the middle of the length as in the last experiment, excepting that the depth was diminished at the ends to one-half of the central depth. This diminution of the depth towards the points of support does not in any degree influence the absolute strength of the beam, but simply increases the deflection. The load which

produced a permanent set was (160 × 12 =) 1920 lbs., as in the last experiments, with a deflection of ·103 and ·1075, the beams being of different weights. The calculated deflection by Tredgold (Art. 193) is $\frac{\cdot 0327\, l^2}{d} = \cdot 1036$, an approximation exceedingly close to No. 6. A very slight difference in the section of No. 7 is sufficient to account for the increased deflection. A difference in the quality of the metal would also affect the result, which is most likely to be the case, as by the table the deflection is in advance from the commencement; and from the weight of the specimen being $\frac{1}{18}$ more than No. 6, the increased density of the metal may account for this discrepancy, as in all cases it is found that the better or softer the metal is the greater the amount of deflection under a given strain. Both causes may however combine to produce the result in No. 6. The breaking weight is to the elastic weight as 511 : 160, or as 3·19 : 1. The coefficient for a beam 1 foot long and 1 inch deep and proportionate section, 461·2.

Experiment V. Nos. 8 and 9.—Were of the same section as the last, the depth at the ends being two-thirds of the central depth.

The permanent set was observed to take place at (158 × 12 =) 1896 lbs., with a deflection of ·105 inch, and ·10625; at (200 × 12 =) 2400 the elasticity was the same in both; the permanent set in No. 8 was ·004, and in No. 9, ·005; the absolute deflections very nearly coinciding, the latter being a heavier casting, and consequently a more extensible material. The breaking weight in this experiment was to the elastic weight as 546 : 158, or as 3·45 : 1. The coefficient for a beam 1 foot long and 1 inch in depth, and of the same proportionate section, 455.

Experiment VI. Nos. 10 and 11.—Were of similar section and character as the last, but with the flanges reversed. The permanent set took place when No. 10 was loaded with (156 × 12 =) 1872 lbs. with a deflection of ·104; comparing this with No. 8, to which it is opposed, being of equal weight, we find that 1896 produced a deflection of ·105, the deflection being nearly in the ratio of the applied weights, confirming most completely the identity of the two positions of the single flanged beam. The ratio of the breaking weight in No. 10 to its elastic weight, cannot be ascertained correctly, as the fracture was accelerated by a large air bubble in the section. No. 11 was too light to compare with the former two, and exhibits a higher degree of deflection, which was owing to the section being reduced by an air bubble, and therefore unfit for comparison, a set of ·004 taking place at (168 × 12 =)

1916 lbs. The coefficient for a beam 1 foot long and 1 inch deep, and of proportionate section, 450.

Experiment VII. Nos. 12 and 13.—Were beams of the open kind, the top and bottom rails being small in proportion to the whole depth. The central depth was 6 inches, the breadth 1 inch, and the width of each rail 1 inch, making the ratio of open part of the beam ·66 of the whole depth, the depth of the ends 3 inches. The object in this experiment was to shew the fallacy of the Galilean theory, which considers the whole of the section of a beam as strained by a tensile force with its neutral point at the upper edge; for this purpose one beam, No. 13, was cast with a part of the upper rail cut out and a piece of steel was nicely fitted and inserted into the opening, so that to substantiate the theory, the piece of steel would be released by the separation of the parts. The beams were in every other respect alike. The load which produced a permanent set in No. 12, was greater than $(574 \times 12 =)$ 6888 lbs. with a deflection a little exceeding ·0825. The weight assigned by Tredgold is $\left(\frac{C\,d^2 b(1-q^3)}{l} = W = \right)$* 7000 lbs. Taking the same load in No. 13, the corresponding deflection is ·081, which is nearly identical with the former, shewing that the upper rail of the section is compressed and not extended. The deflection is somewhat under that of No. 12, arising from the substitution of the steel filling-in piece, which being a harder material than the cast iron, the amount of the compression in the length of the upper rail was less.

It is not expected that the principle need be further insisted upon in this place, as the contrary is so much at variance with common sense†.

Experiment VIII. Nos. 14 and 15.—Were beams of triangular section, being an equilateral triangle of 2 inches base, and were tested with the base upward: they were of equal weight. Although the differences are alike after a few observations, the absolute deflection of each specimen varies at the elastic limit about ·005, or 5 per cent. As No. 14 was not broken, it was not ascertained whether the increased deflection resulted from a defective section. No. 15 was exceedingly sound, as may be seen in the illustrated section of fracture. The load producing the permanent set was $(48 \times 12 =)$ 576 lbs., with a de-

* See note, p. 124.

† A sketch of the several theories which have from time to time engaged the attention of men of science, shewing the progress by which the present principles have been matured, may be seen in Barlow's Essays on the Strength of Timber.

flection of ·112 and ·117, or a mean of ·1145. The load assigned by Tredgold, is $\left(\frac{C\, d^2 b}{3l} = W = \right)$ 566 lbs. with a deflection of ·114, a very near approximation. The ratio of the breaking weight to the elastic weight is 112 : 48, or as 2·33 to 1. The coefficient for a beam 1 foot long and 1 inch deep, from the apex to the opposite side or base of the triangle, is 172.

Experiment IX. Nos. 16 and 17.—Were beams of the same section as last tested with the base downwards. These specimens were nearly of the same weight, and the variation in the amount of deflection was about the same as in the last experiment. The load producing permanent set was (52 × 12 =) 624 lbs. with a deflection of ·115 and ·106, or a mean of ·1105. Comparing these results with those of the last experiments, they will be found to coincide very nearly, and quite as accurately as beams of a probable difference of quality can be expected to do. The ratio of the breaking weight to the elastic weight in No. 17, is as 192 : 52, or as 3·7 : 1. The results of these experiments on beams of triangular sections, corroborate those of the single flange kind.

Experiment X. Nos. 18 and 19.—Were beams similar to Nos. 14 and 15, and tested in the same position; by a comparison with those experiments, we find a very near accordance in the results. The permanent set took place at (48 × 12 =) 576 lbs. with a deflection of ·111 and ·101, or a mean of ·106, which will be found to agree more closely with Nos. 16 and 17 than Nos. 14 and 15, but the differences amount to so small a quantity that it may be disregarded. In these experiments the ratio of the breaking weight to the elastic weight is as 112 and 156 : 48, or as 2·3 and 3·25 : 1.

Experiments XI. and XII. Nos. 20 and 21.—Were open beams of the single flanged kind; the depth in the middle 3 inches, thickness ·625, the flange 1·625 wide and ·625 thick, the open part between the upper and lower rails ·583 of the whole depth; the distance between the upper and lower rails was preserved by occasional vertical bars. Experiment XI. was made with the flange downwards, and Experiment XII. with the flange upwards. The two columns will therefore show the relative value of the two positions. There was a difference in the weight of the two specimens, arising from the additional footing piece in No. 21. By an examination of the results, a most remarkable coincidence will be found throughout the entire range, at the end of which the total difference of the deflections does not exceed ·08 for equal weights. Taking the elastic limit, the load was (76 × 12 =) 912 lbs. with a deflection in No. 20 of ·1335, and in No.

21 of ·138, a difference quite insignificant. The breaking weights are here very small, owing to the peculiar construction of the beams; they are made only for the elastic weight, and the rails were consequently not sufficiently braced to prevent crippling.

Experiment XIII. Nos. 22 and 23.—Were open beams of the same depth and flange, but with a different character of bracing. The same disposition of the strain was observed as in the last pair of experiments. At the elastic limits there is a difference of ·0045 in the deflections for corresponding weights at $(108 \times 12 =)$ 1296 lbs.; but tracing the columns they will be found to coincide exactly as the experiments proceed. In these experiments the small degree of permanent set is very striking, shewing the greater uniformity of the strain upon the sectional area of beams of this order. No. 23 broke with $(400 \times 12 =)$ 4800 lbs. being in the ratio of 2·17 : 1. It is here remarkable that the beam with the flange downwards deflected rather more than that with the flange upwards, (contrary to the usual opinion,) since it is a more convincing proof of the inaccuracy of those opinions which these experiments were originally designed to correct.

Experiment XIV. Nos. 24 and 25.—Were open beams of similar section to the last, but varying in the mode of connecting the rails. There is a discrepancy in these experiments which could only be accounted for by an air bubble in the section, since the deflection is nearly as the weight applied: had the specimen broke across the section, the cause could have been ascertained.

Experiment XV. Nos. 26 and 27.—Were open beams of similar character, but with a different mode of bracing and increased depth. The accordance is here again very striking. The permanent set took place with a load of $(168 \times 12 =)$ 2016 lbs. and a deflection of ·0755 in both cases alike. The relative breaking weights are in the ratio of 592 : 276, or as 2·14 : 1. In all these experiments on open beams, it is obvious that the results all fall short of the full strength of the specimens, as the fracture took place out of the centre.

Experiment XVI. Nos. 28 and 29.—Were solid single flanged beams with the central part cut out so as to leave the same section at the middle as in the last. The depth of these beams was 4 inches in the middle, and 2 inches at the ends, with 3 inches taken out of the middle. A very close agreement subsists up to the elastic limit, which very singularly took place in these specimens so low as $(108 \times 12 =)$ 1296 lbs., the deflection being ·036 and ·039. At $(168 \times 12 =)$ 2016 lbs., in each experiment the permanent set was precisely

the same ·0015, and the absolute deflections were respectively ·051 and ·0525. The ratio of the breaking weights was 540 : 196, or as 2·75 : 1.

In the several comparative specimens of similar open beams, the difference of weight arises in some instances entirely from the addition of the footings, and not from any variation in the dimensions or quality of the specimens. The latter ten experiments were instituted to show the variation of strength by adopting different modes of framing the braces, by which also the proportionate value of the several additions of metal is obtained. The results are tabulated in a separate form at page 124, giving their relative value in terms of a unit in breadth, depth and length, which number is also the coefficient to be used in the formula for the particular form of section, to which it applies in the form of $\frac{C\,b\,d^2}{l} = W$, taking b and d for the extreme breadth and depth.

It is obvious from these experiments that the strength of an open girder very much depends upon the mode of uniting the top and bottom rails, so as to insure a uniformity of strength, in which case the fracture would most probably take place in the middle; this was the case in the last experiments, where the beams were made solid excepting the central part.

It is a striking feature in these experiments, that the results not only accord most minutely with the theoretical deductions of Tredgold, but that they show most completely that the aggregation of the particles of the metal, whether in the smaller or enlarged sections, is nearly the same; since in beams of the largest kind weighing from 4 to 5 tons and upwards, and constructed to sustain a load of from 50 to 150 tons weight, the same degree of fidelity attends the comparison. It is very important to know this, for in a work of such extensive requisition as Tredgold's Essay on Cast Iron, to have a doubt existing of its accuracy in theoretical or practical detail is to involve the practitioner in the most painful perplexity. It is also a source of the highest gratification to be enabled upon this positive testimony to conduce so decidedly to the establishment of such a valuable contribution to science, and to maintain, although it cannot elevate, the character of a man who, by his peculiar acumen and indefatigable industry, has in the very limited period allotted to his scientific labours, enriched so many of the paths of science by eradicating the weeds of empiricism, and in their stead sowing the seeds of principle, founded on the natural laws and affections of matter.

TABLE *of the Comparative Value of the last ten Experiments of the Series.*

No.	Weight of specimen.	Elastic weight.	Deflection.	Breaking weights.	Deflection.	Coefficient.
	lbs.	lbs.		lbs.		
20	15·5	76	·1335	100	·188	192·25
21	16·5	76	·138	98	·190	
22	18·375	108	·070	184	·125	273·24
23	17·375	108	·075	400	·298	
24	15·4	200	·169	284	·250	
25	16·5	100	·095	188	·180	
26	17·125	168	·0755	592	·273	239
27	19·81	168	·0755	276	·1235	
28	21·5	108	·036	540	·204	153·7
29	22·75	108	·039	172	·065	

Taking each pair of specimens, it will be found that the deflections for the breaking weights are in the ratio of those numbers nearly.

In these experiments on open beams the comparative value, as shewn in the Table, of the cases of the flange up or down does not follow any defined or regular law; since with the same section the beams were all of different values. Therefore, a comparison cannot be instituted between the two positions of the beams, as, theoretically, they are, as far as regards their central sections, of equal strength.

NOTE TO PAGE 115.—In these and all the formulæ made use of in this paper, b is the breadth in inches, d the depth in inches at the middle of the length, which is the point of greatest strain; l is the length in feet between the points of support; f is the elastic force per square inch of the material $=15300$ lbs.; and w the weight or load which each specimen is capable of supporting.

NOTE TO PAGE 117.—Taking 1248 lbs. as the elastic power of the specimen, the coefficient is obtained by the formula,

$$\frac{l\,w}{b\,d^2}=\mathrm{C}$$

$$\text{or,}\qquad \frac{3{\cdot}083\times1248}{{\cdot}5\times3^2}=855;$$

and the equivalent elastic force of a square inch is by the formula,

$$\frac{3\,w\,l}{2\,b\,d^2}=f;$$

$$\text{or,}\qquad \frac{3\times1248\times3{\cdot}083\times12}{2\times{\cdot}5\times3^2}=15360\text{ lbs.}$$

where l is taken in inches instead of feet.

NOTE TO PAGE 120.—In this formula, C (the coefficient for 1 foot long, 1 inch deep,) $=850$; and $q={\cdot}66$, the ratio of the open part to the whole depth of the beam.

	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.
	lbs.			lbs.			lbs.			lbs.		
Exp. I.	4	·0025	·002	52	·029	·0025	100	·056	·002	148	·081	·003
No. 1.	8	·0045	·0025	56	·0315	·0022	104	·058*	·002	152	·084	
	12	·007	·003	60	·0337	·0022	108	·060	·003			
	16	·010	·002	64	·036	·002	112	·063	·002			
	20	·012	·002	68	·038	·002	116	·065	·0012			
	24	·014	·002	72	·040	·002	120	·0662	·0022			
	28	·016	·002	76	·042	·002	124	·0685	·0025			
	32	·018	·002	80	·044	·0025	128	·071	·0025			
	36	·020	·002	84	·0465	·0025	132	·0735	·0017			
	40	·022	·002	88	·049	·0025	136	·0752	·0027			
Weight,	44	·024	·0025	92	·0515	·0025	140	·078	·002			
18 bs. 12 oz.	48	·0265	·0025	96	·054	·002	144	·080	·001			
	4	·0015	·0015	84	·0405	·0015	164	·077	·002	350	·164	008
	8	·003	·002	88	·042	·0025	168	·079	·0015	364	·172	·006
	12	·005	·002	92	·0445	·0015	172	·0805	·0015	378	·178	·008
	16	·007	·002	96	·046	·002	176	·082	·001	392	·186	·008
Exp. II.	20	·009	·002	100	·048	·002	180	·083	·001	406	·194	·011
No. 2.	24	·011	·002	104	·050	·0015	184	·084	·001	420	·205	
	28	·013	·002	108	·0515	·002	188	·085	·0012	434	Broke.	
	32	·015	·002	112	·0535	·002	192	·0862	·0017			
	36	·017	·002	116	·0555	·002	196	·088	·002			
	40	·019	·002	120	·0575	·002	200	·090	·008			
	44	·021	·002	124	·0595	·001	210	·098	·004			
	48	·023	·002	128	·0605	·001	224	·102	·006			
	52	·025	·002	132	·0615	·0015	238	·108	·007			
Weight,	56	·027	·0015	136	·063	·002	252	·115	·005			
22 lbs. 4 oz.	60	·0285	·0015	140	·065	·002	266	·120	·006			
	64	·030	·002	144	·067*	·002	280	·126	·006			
	68	·032	·0025	148	·069	·002	294	·132	·005			
	72	·0345	·002	152	·071	·002	308	·137	·005			
	76	·0365	·002	156	·073	·002	322	·142	·006			
	80	·0385	·002	160	·075	·002	336	·148	·016			
	4	·0015	·0015	64	·027	·0015	124	·0515	·0015	184	·0755	·0015
	8	·003	·0022	68	·0285	·0015	128	·053	·0017	188	·077	·001
	12	·0052	·0022	72	·030	·002	132	·0547	·0017	192	·078	·0015
No. 3.	16	·0075	·002	76	·032	·001	136	·0565	·0015	196	·0795	·0015
	20	·0095	·002	80	·033	·0015	140	·058	·0015	200	·081	
	24	·0115	·0015	84	·0345	·0015	144	·0595	·0015			
	28	·013	·002	88	·036	·0017	148	·061	·0015			
	32	·015	·001	92	·0377	·002	152	·0625	·0015			
	36	·016	·0015	96	·0397	·0012	156	·064	·0015			
	40	·0175	·0015	100	·041	·0015	160	·0655*	·002			
	44	·019	·0015	104	·0425	·002	164	·0675	·002			
Weight,	48	·0205	·0015	108	·0445	·0015	168	·0695	·0015			
21 lbs. 4 oz.	52	·022	·0015	112	·046	·0015	172	·071	·0015			
	56	·0235	·0015	116	·0475	·002	176	·0725	·0015			
	60	·025	·002	120	·0495	·002	180	·074	·0015			

Exp. III.

No. 4.

Weight, 21 lbs. 2 oz.

Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.
lbs.			lbs.			lbs.			lbs.		
4	·001	·002	68	·0295	·0015	132	·0577	·0012	196	·088	·002
8	·003	·002	72	·031	·002	136	·059	·0015	200	·090	·007
12	·005	·0025	76	·033	·002	140	·0605	·0045	210	·097	·008
16	·0075	·0015	80	·035	·002	144	·065	·0015	224	·105	·008
20	·009	·002	84	·037	·0015	148	·0665	·0015	238	·113	·004
24	·011	·002	88	·0385	·0015	152	·068	·001	252	·117	·005
28	·013	·0015	92	·040	·002	156	·069	·0015	266	·122	·010
32	·0145	·0015	96	·042	·002	160	·0705*	·003	280	·132	·005
36	·016	·0015	100	·044	·0015	164	·0735	·0015	294	·137	·010
40	·0175	·0015	104	·0455	·002	168	·075	·002	308	·147	·010
44	·019	·0015	108	·0475	·0015	172	·077	·002	322	·157	·009
48	·0205	·002	112	·049	·0015	176	·079	·002	336	·166	·008
52	·0225	·0025	116	·0505	·002	180	·081	·001	350	·174	·009
56	·025	·0015	120	·0525	·0015	184	·082	·002	364	·183	
60	·0265	·0015	124	·054	·0015	188	·084	·002	378	Broke.	
64	·028	·0015	128	·0555	·0022	192	·086	·002			

No. 5.

Weight, 20 lbs. 8 oz.

Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.
4	·0015	·002	56	·028	·002	108	·053	·002	160	·0755	·0015
8	·0035	·0025	60	·030	·002	112	·055	·002	164	·077	·003
12	·006	·002	64	·032	·002	116	·057	·002	168	·080	·0035
16	·008	·002	68	·034	·001	120	·059	·0015	172	·0835	·0015
20	·010	·0025	72	·035	·002	124	·0605	·002	176	·085	·0015
24	·0125	·0025	76	·037	·002	128	·0625	·002	180	·0865	·002
28	·015	·0015	80	·039	·002	132	·0645	·0015	184	·0885	·0025
32	·0165	·0025	84	·041	·002	136	·066	·0015	188	·091	·0025
36	·019	·001	88	·043	·002	140	·0675	·0015	192	·0935	·002
40	·020	·002	92	·045	·002	144	·069	·002	196	·0955	·0015
44	·022	·002	96	·047	·002	148	·071	·0015	200	·097	
48	·024	·0015	100	·049	·002	152	·0725*	·0015			
52	·0255	·0025	104	·051	·002	156	·074	·0015			

Exp. IV.

No. 6.

Weight, 17 lbs. 0 oz.

Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.
4	·002	·003	80	·0525	·0025	156	·100	·003	308	·205	·007
8	·005	·003	84	·055	·0025	160	·103*	·0025	322	·212	·007
12	·008	·003	88	·0575	·0025	164	·1055	·0025	336	·219	·008
16	·011	·003	92	·060	·0025	168	·108	·003	350	·227	·010
20	·014	·002	96	·0625	·0025	172	·111	·003	364	·237	·010
24	·016	·003	100	·065	·0025	176	·114	·002	378	·247	·010
28	·019	·0025	104	·0675	·0025	180	·116	·003	392	·257	
32	·0215	·0025	108	·070	·0025	184	·119	·003	406		
36	·024	·0025	112	·0725	·0025	188	·122	·003	420		
40	·0265	·0025	116	·075	·0025	192	·125	·003	434		
44	·029	·003	120	·0775	·0025	196	·128	·004	448		
48	·032	·002	124	·080	·0025	200	·132	·003	462		
52	·034	·003	128	·0825	·0025	210	·135	·010	476		
56	·037	·003	132	·085	·0025	224	·145	·010	490		
60	·040	·002	136	·0875	·0025	238	·155	·010	504		
64	·042	·003	140	·090	·002	252	·165	·010	511	Broke.	
68	·045	·0025	144	·092	·003	266	·175	·010			
72	·0475	·0025	148	·095	·003	280	·185	·010			
76	·050	·0025	152	·098	·002	294	·195	·010			

	Weights applied.	Deflec-tions.	Differ-ences.	Weights applied.	Deflec-tions.	Differ-ences.	Weights applied.	Deflec-tions.	Differ-ences.	Weights applied.	Deflec-tions.	Differ-ences.
	lbs.			lbs.			lbs.			lbs.		
	4	·003	·003	56	·042	·003	108	·075	·002	160	·1075*	·0035
No. 7.	8	·006	·003	60	·045	·003	112	·077	·003	164	·111	·004
	12	·009	·003	64	·048	·002	116	·080	·0025	168	·115	·0015
	16	·012	·003	68	·050	·003	120	·0825	·0025	172	·1165	·0025
	20	·015	·003	72	·053	·003	124	·085	·003	176	·119	·003
	24	·018	·003	76	·056	·002	128	·088	·003	180	·122	·003
	28	·021	·004	80	·058	·002	132	·091	·002	184	·125	·002
	32	·025	·003	84	·060	·0025	136	·093	·002	188	·127	·003
	36	·028	·003	88	·0625	·0025	140	·095	·0025	192	·130	·0025
Weight,	40	·031	·003	92	·065	·002	144	·0975	·0025	196	·1325	·0025
18 lbs. 0 oz.	44	·034	·003	96	·067	·0025	148	·100	·003	200	·135	
	48	·037	·003	100	·0695	·0015	152	·103	·002			
	52	·040	·002	104	·071	·004	156	·105	·0025			
	4	·003	·004	84	·0605	·0015	164	·1095	·0035	350	·230	·010
	8	·007	·003	88	·062	·004	168	·113	·002	364	· 40	·011
	12	·010	·003	92	·066	·002	172	·115	·002	378	·251	·011
	16	·013	·003	96	·068	·002	176	·117	·003	392	·262	·011
	20	·016	·004	100	·070	·003	180	·120	·003	406	·273	·011
Exp. V.	24	·020	·0035	104	·073	·003	184	·123	·002	420	·284	·011
No. 8.	28	·0235	·0025	108	·076	·002	188	·125	·003	434	·295	·011
	32	·026	·003	112	·078	·003	192	·128	·003	448	·306	·011
	36	·029	·003	116	·081	·003	196	·131	·003	462	·317	·012
	40	·032	·003	120	·084	·001	200	·134	·003	476	·328	·012
	44	·035	·0025	124	·085	·0025	210	·137	·007	490	·340	·024
	48	·0375	·0025	128	·0875	·0015	224	·144	·008	504	·352	·017
	52	·040	·002	132	·089	·0025	238	·152	·009	518	·376	
	56	·042	·0025	136	·0915	·0035	252	·161	·010	532	·393	
Weight,	60	·0445	·0025	140	·095	·0025	266	·171	·010	546	Broke.	
17 lbs. 12 oz.	64	·047	·003	144	·0975	·0025	280	·181	·009			
	68	·050	·0025	148	·100	·002	294	·190	·010			
	72	·0525	·0025	152	·102	·002	308	·200	·010			
	76	·055	·003	156	·104	·002	322	·210	·010			
	80	·058	·0025	160	·106*	·0035	336	·220	·010			
	4	·002	·003	60	·040	·003	116	·078	·0025	172	·114	·002
	8	·005	·003	64	·043	·0025	120	·0805	·0025	176	·116	·0025
No. 9.	12	·008	·003	68	·0455	·003	124	·083	·003	180	·1185	·0025
	16	·011	·003	72	·0485	·0025	128	·086	·003	184	·121	·002
	20	·014	·003	76	·051	·0025	132	·089	·002	188	·123	·003
	24	·017	·003	80	·0535	·0025	136	·091	·003	192	·126	·002
	28	·020	·003	84	·056	·003	140	·094	·003	196	·128	·003
	32	·023	·002	88	·059	·0025	144	·097	·003	200	·131	
	36	·025	·003	92	·0615	·0025	148	·100	·003			
	40	·028	·0025	96	·064	·003	152	·103	·0025			
Weight,	44	·0305	·0025	100	·067	·003	156	·1055	·0015			
18 lbs. 4 oz.	48	·033	·003	104	·070	·002	160	·107*	·003			
	52	·036	·002	108	·072	·003	164	·110	·0025			
	56	·038	·002	112	·075	·003	168	·1125	·0015			

	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.
	lbs.			lbs.			lbs.			lbs.		
Exp. VI.	4	·0015	·0025	72	·0465	·003	140	·0925	·0025	224	·151	·0115
No. 10.	8	·004	·003	76	·0495	·0025	144	·095	·003	238	·1625	·0115
	12	·007	·0025	80	·052	·003	148	·098	·003	252	·174	·012
	16	·0095	·0025	84	·055	·003	152	·101	·003	266	·186	·013
	20	·012	·003	88	·058	·0025	156	·104*	·003	280	·199	
	24	·015	·0025	92	·0605	·0025	160	·107	·003	294	Broke.	
	28	·0175	·0015	96	·063	·003	164	·110	·0035			
	32	·019	·003	100	·066	·002	168	·1135	·0025			
	36	·022	·003	104	·068	·002	172	·116	·003			
	40	·025	·003	108	·070	·003	176	·119	·004			
	44	·028	·003	112	·073	·003	180	·123	·002			
	48	·031	·002	116	·076	·002	184	·125	·0025			
Weight, 17 lbs. 8 oz.	52	·033	·003	120	·078	·003	188	·1275	·0035			
	56	·036	·003	124	·081	·003	192	·131	·0025			
	60	·039	·002	128	·084	·003	196	·1335	·0035			
	64	·041	·0025	132	·087	·003	200	·137*	·005			
	68	·0435	·003	136	·090	·0025	210	·142	·009			
	4	·0015	·0035	64	·0485	·003	124	·0955	·0025	184	·147	·003
	8	·005	·003	68	·0515	·003	128	·098	·003	188	·150	·003
No. 11.	12	·008	·003	72	·0545	·003	132	·101	·0045	192	·153	·003
	16	·011	·003	76	·0575	·0035	136	·1055	·0025	196	·156	·003
	20	·014	·003	80	·061	·003	140	·108	·0045	200	·159	
	24	·017	·004	84	·064	·003	144	·1125	·0025			
	28	·021	·003	88	·067	·003	148	·115	·003			
	32	·024	·0035	92	·070	·004	152	·118	·005			
	36	·0275	·003	96	·074	·003	156	·123	·003			
	40	·0305	·003	100	·077	·003	160	·126	·003			
Weight, 17 lbs. 0 oz.	44	·0335	·0035	104	·080	·003	164	·129	·005			
	48	·037	·003	108	·083	·002	168	·134	·003			
	52	·040	·003	112	·085	·004	172	·137	·003			
	56	·043	·0025	116	·089	·0035	176	·140	·004			
	60	·0455	·003	120	·0925	·003	180	·144	·003			
Exp. VII. No. 12.	28	·003	·0015	210	·027	·002	392	·0535	·0015	574	·0825*	·0025
	42	·0045	·002	224	·029	·002	406	·055	·003	588	·085	·003
	56	·0065	·0015	238	·031	·0015	420	·058	·002	602	·088	
	70	·008	·002	252	·0325	·002	434	·060	·0025			
	84	·010	·002	266	·0345	·0015	448	·0625	·002			
	98	·012	·002	280	·036	·002	462	·0645	·0025			
	112	·014	·0015	294	·038	·002	476	·067	·002			
	126	·0155	·002	308	·040	·0025	490	·069	·003			
	140	·0175	·002	322	·0425	·0025	504	·072	·0015			
	154	·0195	·0015	336	·045	·0025	528	·0735	·002			
	168	·021	·002	350	·0475	·002	532	·0755	·0025			
	182	·023	·0015	364	·0495	·0015	546	·078	·002			
Weight, 29 lbs. 4 oz.	196	·0245	·0025	378	·051	·0025	560	·080	·0025			

	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.
No. 13.  Weight, 29 lbs. 4 oz.	lbs.			lbs.			lbs.			lbs.		
	14	·0025	·0025	168	·0255	·002	322	·0465	·0025	476	·067	·002
	28	·005	·0015	182	·0275	·002	336	·049	·002	490	·069	·002
	42	·0065	·0025	196	·0295	·0015	350	·051	·002	504	·071	·002
	56	·009	·002	210	·031	·002	364	·053	·0015	518	·073	·002
	70	·011	·0025	224	·033	·002	378	·0545	·0015	532	·075	·002
	84	·0135	·0015	238	·035	·002	392	·056	·0015	546	·077	·002
	98	·015	·002	252	·037	·002	406	·0575	·002	560	·079	·002
	112	·017	·002	266	·039	·002	420	·0595	·0015	574	·081*	·002
	126	·019	·0025	280	·041	·0025	434	·061	·002	588	·083	·002
	140	·0215	·002	294	·0435	·0015	448	·063	·002	602	·085	
	154	·0235	·002	308	·045	·0015	462	·065	·002			
Ex. VIII. N°. 14.  21 lbs. 4 oz.	4	·009	·009	20	·045	·009	36	·085	·010	52	·128	·013
	8	·018	·009	24	·054	·009	40	·095	·011	56	·141	
	12	·027	·009	28	·063	·010	44	·106	·011			
	16	·036	·009	32	·073	·012	48	·117*	·011			
No. 15.  Weight, 21 lbs. 4 oz.	4	·008	·008	32	·068	·011	60	·148	·012	88	·234	·012
	8	·016	·008	36	·079	·011	64	·160	·012	92	·246	·013
	12	·024	·008	40	·090	·011	68	·172	·012	96	·259	·013
	16	·032	·008	44	·101	·011	72	·184	·012	100	·272	·014
	20	·040	·008	48	·112*	·011	76	·196	·014	104	·286	·014
	24	·048	·010	52	·123	·013	80	·210	·012	108	·300	
	28	·058	·010	56	·136	·012	84	·222	·012	112	Broke.	
Exp. IX. No. 16.  Weight, 18 lbs. 12 oz.	2	·004	·004	18	·035	·004	34	·067	·0045	50	·103	·003
	4	·008	·004	20	·039	·004	36	·0715	·0035	52	·106*	·003
	6	·012	·003	22	·043	·004	38	·075	·005	54	·109	.004
	8	·015	·004	24	·047	·004	40	·080	·005	56	·113	·005
	10	·019	·004	26	·051	·004	42	·085	·005	58	·118	·004
	12	·023	·005	28	·055	·0045	44	·090	·005	60	·122	
	14	·028	·003	30	·0595	·0035	46	·095	·004			
	16	·031	·004	32	·063	·004	48	·099	·004			
No. 17.  Weight, 19 lbs. 0 oz.	2	·004	·004	34	·072	·005	72	·155	·008	136	·291	·008
	4	·008	·004	36	·077	·005	76	·163	·008	140	·299	·009
	6	·012	·004	38	·082	·005	80	·171	·008	144	·308	·008
	8	·016	·004	40	·087	·005	84	·179	·009	148	·316	·008
	10	·020	·004	42	·092	·005	88	·188	·007	152	·324	·009
	12	·024	·004	44	·097	·005	92	·195	·010	156	·333	·008
	14	·028	·004	46	·102	·004	96	·205	·009	160	·341	·009
	16	·032	·004	48	·106	·004	100	·214	·009	164	·350	·008
	18	·036	·005	50	·110	·005	104	·223	·009	168	·358	·009
	20	·041	·0045	52	·115*	·005	108	·232	·008	172	·367	·010
	22	·0455	·0040	54	·120	·005	112	·240	·009	176	·377	·011
	24	·0495	·0045	56	·125	·004	116	·249	·008	180	·388	·010
	26	·054	·004	58	·129	·004	120	·257	·008	184	·398	·002
	28	·058	·0045	60	·133	·007	124	·265	·009	188	·400	
	30	·0625	·0045	64	·140	·007	128	·274	·008	192	Broke.	
	32	·067	·005	68	·147	·008	132	·282	·009			

	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.
	lbs.			lbs.			lbs.			lbs.		
Exp. X.	2	·004	·003	30	·0655	·0055	58	·136	·006	86	·221	·007
No. 18.	4	·007	·003	32	·071	·005	60	·142	·006	88	·228	·006
	6	·010	·004	34	·076	·005	62	·148	·007	90	·234	·006
Weight, 21 lbs. 8 oz.	8	·014	·0045	36	·081	·005	64	·155	·007	92	·240	·007
	10	·0185	·0055	38	·086	·005	66	·162	·006	94	·247	·007
	12	·024	·0045	40	·091	·005	68	·168	·005	96	·254	·007
	14	·0285	·0045	42	·096	·005	70	·173	·006	98	·261	·007
	16	·033	·004	44	·101	·005	72	·179	·006	100	·268	·007
	18	·037	·005	46	·106	·005	74	·185	·006	102	·275	·007
	20	·042	·005	48	·111*	·005	76	·191	·006	104	·282	·007
	22	·047	·005	50	·116	·005	78	·197	·006	106	·289	·007
	24	·052	·004	52	·121	·005	80	·203	·006	108	·296	·007
	26	·056	·0045	54	·126	·005	82	·209	·006	110	·303	
	28	·0605	·005	56	·131	·005	84	·215	·006	112	Broke.	
No. 19.	2	·004	·003	42	·089	·005	82	·184	·006	122	·309	·009
	4	·007	·003	44	·094	·0035	84	·190	·006	124	·318	·007
Weight, 21 lbs. 4 oz.	6	·010	·0035	46	·0975	·0035	86	·196	·006	126	·325	·006
	8	·0135	·0035	48	·101*	·004	88	·202	·006	128	·331	·006
	10	·017	·004	50	·105	·004	90	·208	·006	130	·337	·007
	12	·021	·005	52	·109	·004	92	·214	·006	132	·344	·008
	14	·026	·0045	54	·113	·004	94	·220	·006	134	·352	·008
	16	·0305	·0045	56	·117	·0035	96	·226	·006	136	·360	·007
	18	·035	·004	58	·120	·0045	98	·232	·006	138	·367	·008
	20	·039	·004	60	·125	·005	100	·238	·006	140	·375	·008
	22	·043	·004	62	·130	·005	102	·244	·006	142	·383	·006
	24	·047	·004	64	·135	·005	104	·250	·006	146	·389	·007
	26	·051	·004	66	·140	·006	106	·256	·006	148	·396	·009
	28	·055	·004	68	·146	·005	108	·262	·007	150	·405	·009
	30	·059	·005	70	·151	·006	110	·269	·006	152	·414	·010
	32	·064	·005	72	·157	·006	112	·275	·006	154	·424	·010
	34	·069	·005	74	·163	·005	114	·281	·006	156	·434	
	36	·074	·005	76	·168	·005	116	·287	·006		Broke.	
	38	·079	·005	78	·173	·006	118	·293	·007			
	40	·084	·005	80	·179	·005	120	·300	·009			
Exp. XI.	2	·003	·0035	28	·0505	·0035	54	·0955	·0035	80	·1445	·0035
No. 20.	4	·0065	·0035	30	·054	·0035	56	·099	·0035	82	·148	·004
	6	·010	·004	32	·0575	·003	58	·1025	·0035	84	·152	·004
Weight, 15 lbs. 8 oz.	8	·014	·004	34	·0605	·0035	60	·106	·0035	86	·156	·004
	10	·018	·004	36	·064	·0035	62	·1095	·0035	88	·160	·004
	12	·022	·004	38	·0675	·0035	64	·113	·0035	90	·164	·0045
	14	·026	·004	40	·071	·0035	66	·1165	·0025	92	·1685	·0045
	16	·030	·004	42	·0745	·0035	68	·119	·003	94	·173	·005
	18	·034	·0035	44	·078	·0035	70	·122	·0045	96	·178	·004
	20	·0375	·0035	46	·0815	·0035	72	·1265	·0035	98	·182	·006
	22	·041	·003	48	·085	·0035	74	·130	·0035	100	·188	
	24	·044	·0035	50	·0885	·0035	76	·1335*	·0045		Broke.	
	26	·0475	·003	52	·092	·0035	78	·138	·0065			

	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.
	lbs.			lbs.			lbs.			lbs.		
Exp. XII.	2	·003	·0025	28	·0485	·003	54	·096	·004	80	·146	·005
No. 21.	4	·0055	·0025	30	·0515	·0035	56	·100	·004	82	·151	·0045
	6	·008	·003	32	·055	·004	58	·104	·0035	84	·1555	·0045
	8	·011	·004	34	·059	·0035	60	·1075	·0025	86	·160	·004
	10	·015	·004	36	·0625	·004	62	·110	·0035	88	·164	·005
	12	·019	·004	38	·0665	·0035	64	·1135	·003	90	·169	·005
	14	·023	·0035	40	·070	·0035	66	·1165	·0035	92	·174	·005
	16	·0265	·0035	42	·0735	·004	68	·120	·004	94	·179	·005
	18	·030	·0035	44	·0775	·0035	70	·124	·004	96	·184	·006
Weight, 16 lbs. 8 oz.	20	·0335	·004	46	·081	·004	72	·128	·005	98	·190	
	22	·0375	·0035	48	·085	·004	74	·133	·005		Broke.	
	24	·041	·004	50	·089	·004	76	·138*	·004			
	26	·045	·0035	52	·093	·003	78	·142	·004			

	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.
Exp. XIII.	4	·002	·002	52	·0325	·0025	100	·0625	·0025	148	·098	·003
No. 22.	8	·004	·002	56	·035	·0025	104	·065	·0025	152	·101	·004
	12	·006	·003	60	·0375	·0025	108	·0675	·0025	156	·105	·004
	16	·009	·002	64	·040	·0025	112	·070*	·003	160	·109	·003
	20	·011	·003	68	·0425	·0025	116	·073	·003	164	·112	·003
	24	·014	·003	72	·045	·0025	120	·076	·003	168	·115	·0025
	28	·017	·003	76	·0475	·0025	124	·079	·0035	172	·1175	·0025
	32	·020	·0025	80	·050	·002	128	·0825	·0035	176	·120	·0025
	36	·0225	·0025	84	·052	·003	132	·086	·003	180	·1225	
Weight, 18 lbs. 6 oz.	40	·025	·0025	88	·055	·0025	136	·089	·003	184	Broke.	
	44	·0275	·0025	92	·0575	·0025	140	·092	·003			
	48	·030	·0025	96	·060	·002	144	·095	·003			

	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.
	4	·0025	·0025	104	·069	·003	204	·140	·003	304	·221	·003
	8	·005	·0025	108	·072	·003	208	·143	·003	308	·224	·003
	12	·0075	·0025	112	·075*	·002	212	·146	·004	312	·227	·003
	16	·010	·0025	116	·077	·002	216	·150	·003	316	·230	·0025
	20	·0125	·0025	120	·079	·002	220	·153	·003	320	·2325	·0025
	24	·015	·0025	124	·081	·002	224	·156	·004	324	·235	·004
	28	·0175	·0025	128	·083	·003	228	·160	·003	328	·239	·003
	32	·020	·0025	132	·086	·003	232	·163	·003	332	·242	·003
No. 23.	36	·0225	·0025	136	·089	·003	236	·166	·004	336	·245	·004
	40	·025	·003	140	·092	·003	240	·170	·003	340	·249	·004
	44	·028	·003	144	·095	·003	244	·173	·003	344	·253	·003
	48	·031	·003	148	·098	·003	248	·176	·003	348	·256	·003
	52	·034	·003	152	·101	·003	252	·179	·003	352	·259	·003
	56	·037	·003	156	·104	·003	256	·182	·004	356	·262	·003
	60	·040	·0025	160	·107	·003	260	·186	·004	360	·265	·003
Weight, 17 lbs. 6 oz.	64	·0425	·0025	164	·110	·003	264	·190	·003	364	·268	·003
	68	·045	·0025	168	·113	·003	268	·193	·003	368	·271	·004
	72	·0475	·0025	172	·116	·003	272	·196	·003	372	·275	·003
	76	·050	·0025	176	·119	·003	276	·199	·003	376	·278	·004
	80	·0525	·0025	180	·122	·003	280	·202	·003	380	·282	·004
	84	·055	·0025	184	·125	·003	284	·205	·003	384	·286	·003
	88	·0575	·0025	188	·128	·003	288	·208	·003	388	·289	·003
	92	·060	·003	192	·131	·003	292	·211	·004	392	·292	·003
	96	·063	·003	196	·134	·003	296	·215	·003	396	·295	
	100	·066	·003	200	·137	·003	300	·218	·003	400	Broke.	

	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.
	lbs.			lbs.			lbs.			lbs.		
	4	·003	·003	7	·064	·003	148	·1225	·0035	220	·186	·004
	8	·006	·003	80	·067	·003	152	·126	·0035	224	·190	·004
	12	·009	·003	84	·070	·003	156	·1295	·0025	228	·194	·004
Exp. XIV.	16	·012	·004	88	·073	·003	160	·132	·004	232	·198	·004
No. 24.	20	·016	·004	92	·076	·003	164	·136	·003	236	·202	·004
	24	·020	·0035	96	·079	·003	168	·139	·004	240	·206	·004
	28	·0235	·0035	100	·082	·003	172	·143	·0035	244	·210	·004
	32	·027	·003	104	·085	·003	176	·1465	·0035	248	·214	·004
	36	·030	·004	108	·088	·003	180	·150	·003	252	·218	·004
	40	·034	·004	112	·091	·003	184	·153	·004	256	·222	·004
	44	·038	·003	116	·094	·003	188	·157	·004	260	·226	·004
	48	·041	·003	120	·097	·003	192	·161	·004	264	·230	·004
Weight, 15 lbs. 7 oz.	52	·044	·004	124	·100	·003	196	·165	·004	268	·234	·004
	56	·048	·004	128	·103	·0035	200	·169	·004	272	·238	·004
	60	·052	·003	132	·1065	·0035	204	·173	·004	276	·242	·004
	64	·055	·003	136	·110	·0035	208	·177	·003	280	·246	
	68	·058	·003	140	·1135	·0035	212	·180	·003	284	Broke.	
	72	·061	·003	144	·117	·0055	216	·183	·003			
	4	·003	·003	52	·049	·004	100	·095	·008	148	·144	·004
No. 25.	8	·006	·004	56	·053	·004	104	·103	·003	152	·148	·004
	12	·010	·004	60	·057	·004	108	·106	·0035	156	·152	·004
	16	·014	·004	64	·061	·004	112	·1095	·0035	160	·156	·004
	20	·018	·004	68	·065	·004	116	·113	·003	164	·160	·004
	24	·022	·004	72	·069	·004	120	·116	·004	168	·164	·004
	28	·026	·004	76	·073	·004	124	·120	·004	172	·168	·004
	32	·030	·004	80	·077	·004	128	·124	·004	176	·172	·004
	36	·034	·004	84	·081	·004	132	·128	·003	180	·176	·004
Weight, 16 lbs. 8 oz.	40	·038	·004	88	·085	·003	136	·131	·004	184	·180	
	44	·042	·003	92	·088	·0035	140	·135	·005	188	Broke.	
	48	·045	·004	96	·0915	·0035	144	·140	·004			
	4	·0015	·0015	80	·0375	·0015	156	·0695	·002	232	·104	·0015
	8	·003	·0015	84	·039	·0015	160	·0715	·002	236	·1055	·0015
Exp. XV.	12	·0045	·0015	88	·0405	·0015	164	·0735	·002	240	·107	·0015
No. 26.	16	·006	·002	92	·042	·0015	168	·0755*	·002	244	·1085	·0015
	20	·008	·002	96	·0435	·0015	172	·0775	·002	248	·110	·0015
	24	·010	·002	100	·045	·002	176	·0795	·0015	252	·1115	·0015
	28	·012	·002	104	·047	·002	180	·081	·002	256	·113	·0015
	32	·014	·002	108	·049	·002	184	·083	·002	260	·1145	·0015
	36	·016	·0025	112	·051	·0015	188	·085	·002	264	·116	·001
	40	·0185	·0025	116	·0525	·0015	192	·087	·0015	268	·117	·0015
	44	·021	·002	120	·054	·0015	196	·0885	·0015	272	·1185	·0015
	48	·023	·002	124	·0555	.0015	200	·090	·0015	276	·120	·0015
	52	·025	·002	128	·057	·002	204	·0915	·0015	280	·1215	·0015
	56	·027	·0015	132	·059	·002	208	·093	·0025	284	·123	·002
Weight, 17 lbs. 2 oz.	60	·0285	·002	136	·061	·0015	212	·0955	·002	288	·125	·0015
	64	·0305	·0015	140	·0625	·002	216	·0975	·002	292	·1265	·0015
	68	·032	·002	144	·0645	·0015	220	·0995	·0015	296	·128	·002
	72	·034	·002	148	·066	·0015	224	·101	·0015	300	·130	·0015
	76	·036	·0015	152	·0675	·002	228	·1025	·0015	304	·131	·0015

	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.
	lbs.			lbs.			lbs.			lbs.		
Exp. XV.	308	·133	·002	380	·167	·002	452	·202	·002	524	·238	·002
No. 26.	312	·135	·002	384	·169	·002	456	·204	·002	528	·240	·002
CONTINUED.	316	·137	·002	388	·171	·0015	460	·206	·002	532	·242	·002
Weight, 17 lbs. 2 oz.	320	·139	·002	392	·1725	·0015	464	·208	·002	536	·244	·002
	324	·141	·002	396	·174	·0025	468	·210	·002	540	·246	·002
	328	·143	·002	400	·1765	·0025	472	·212	·002	544	·248	·003
	332	·145	·002	404	·179	·002	476	·214	·0015	548	·251	·003
	336	·147	·002	408	·181	·002	480	·2155	·0015	552	·254	·002
	340	·149	·002	412	·183	·002	484	·217	·002	556	·256	·002
	344	·151	·002	416	·185	·002	488	·219	·002	560	·258	·002
	348	·153	·0015	420	·187	·002	492	·221	·002	564	·260	·002
	352	·1545	·0015	424	·189	·002	496	·223	·002	568	·262	·002
	356	·156	·002	428	·191	·002	500	·225	·003	572	·264	·002
	360	·158	·002	432	·193	·002	504	·228	·002	576	·266	·0015
	364	·160	·002	436	·195	·0015	508	·230	·002	580	·2675	·0015
	368	·162	·002	440	·1965	·0015	512	·232	·002	584	·269	·002
	372	·164	·0015	444	·198	·002	516	·234	·002	588	·271	
	376	·1655	·0015	448	·200	·002	520	·236	·002	592	Broke.	
	4	·0015	·0015	76	·0335	·0015	148	·0655	·002	220	·0975	·002
	8	·003	·0015	80	·035	·002	152	·0675	·002	224	·0995	·001
	12	·0045	·0015	84	·037	·002	156	·0695	·002	228	·1005	·0015
No. 27.	16	·006	·0015	88	·039	·002	160	·0715	·0025	232	·102	·002
	20	·0075	·0015	92	·041	·002	164	·074	·0015	236	·104	·0015
	24	·009	·0015	96	·043	·0015	168	·0755*	·0015	240	·1055	·002
	28	·0105	·0015	100	·0445	·0015	172	·077	·0015	244	·1075	·002
	32	·012	·002	104	·046	·002	176	·0785	·0015	248	·1095	·002
	36	·014	·002	108	·048	·002	180	·080	·0015	252	·1115	·002
	40	·016	·002	112	·050	·0015	184	·0815	·0015	256	·1135	·002
	44	·018	·002	116	·0515	·0015	188	·083	·0015	260	·1155	·002
	48	·020	·002	120	·053	·0015	192	·0845	·0015	264	·1175	·002
	52	·022	·002	124	·0545	·0015	196	·086	·002	268	·1195	·0015
Weight, 19 lbs. 3 oz.	56	·024	·002	128	·056	·0015	200	·088	·002	272	·121	
	60	·026	·002	132	·0575	·002	204	·090	·0015	276	Broke.	
	64	·028	·002	136	·0595	·002	208	·0915	·002			
	68	·030	·002	140	·0615	·002	212	·0935	·002			
	72	·032	·0015	144	·0635	·002	216	·0955	·002			
Exp. XVI.	4	·0015	·0015	48	·016	·0015	92	·031	·0015	136	·043	·001
No. 28.	8	·003	·001	52	·0175	·0015	96	·0325	·0015	140	·044	·001
	12	·004	·001	56	·019	·0015	100	·034	·001	144	·045	·001
	16	·005	·0015	60	·0205	·0015	104	·035	·001	148	·046	·001
	20	·0065	·0015	64	·022	·0015	108	·036*	·001	152	·047	·001
	24	·008	·001	68	·0235	·0015	112	·037	·001	156	·048	·001
	28	·009	·001	72	·025	·0015	116	·038	·001	160	·049	·001
	32	·010	·0015	76	·0265	·0015	120	·039	·001	164	·050	·001
	36	·0115	·0015	80	·0275	·0015	124	·040	·001	168	·051	·001
	40	·013	·0015	84	·029	·001	128	·041	·001	172	·052	·001
Weight, 21 lbs. 8 oz.	44	·0145	·0015	88	·030	·001	132	·042	·001	176	·053	·001

	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.	Weights applied.	Deflections.	Differences.
	lbs.			lbs.			lbs.			lbs.		
Exp. XVI.	180	·054	·001	272	·087	·0015	364	·122	·0015	456	·1635	·002
No. 28.	184	·055	·001	276	·0885	·0015	368	·1235	·0015	460	·1655	·0015
CONTINUED.	188	·056	·0015	280	·090	·001	372	·125	·0015	464	·167	·002
Weight, 21 lbs. 8 oz.	192	·0575	·0015	284	·091	·001	376	·1265	·002	468	·169	·002
	196	·059	·0015	288	·092	·0015	380	·1285	·0015	472	·171	·002
	200	·0605	·0015	292	·0935	·0015	384	·130	·0015	476	·173	·002
	204	·062	·0015	296	·095	·001	388	·1315	·0015	480	·175	·002
	208	·0635	·0015	300	·096	·0015	392	·133	·0015	484	·177	·002
	212	·065	·0015	304	·0975	·0015	396	·1345	·0015	488	·179	·0015
	216	·0665	·0015	308	·099	·0015	400	·136	·0015	492	·1805	·0015
	220	·068	·0015	312	·1005	·0015	404	·1375	·002	496	·182	·002
	224	·0695	·0015	316	·102	·0015	408	·1395	·002	500	·184	·002
	228	·071	·0015	320	·1035	·0015	412	·1415	·002	504	·186	·002
	232	·0725	·001	324	·105	·0015	416	·1435	·002	508	·188	·002
	236	·0735	·0015	328	·1065	·0015	420	·1455	·002	512	·190	·002
	240	·075	·0015	332	·108	·002	424	·1475	·002	516	·192	·002
	244	·0765	·0015	336	·110	·002	428	·1495	·002	520	·194	·002
	248	·078	·0015	340	·112	·002	432	·1515	·002	524	·196	·002
	252	·0795	·0015	344	·114	·0015	436	·1535	·002	528	·198	·002
	256	·081	·0015	348	·1155	·002	440	·1555	·002	532	·200	·002
	260	·0825	·0015	352	·1175	·0015	444	·1575	·002	536	·202	
	264	·084	·0015	356	·119	·0015	448	·1595	·002	540	Broke.	
	268	·0855	·0015	360	·1205	·0015	452	·1615	·002			
No. 29.	4	·001	·0015	56	·0195	·0015	108	·039	·0015	160	·0495	·0015
	8	·0025	·0015	60	·021	·0015	112	·0315	·0015	164	·051	·0015
	12	·004	·001	64	·0225	·0015	116	·033	·0015	168	·0525	·0015
	16	·005	·001	68	·024	·0015	120	·0345	·0015	172	·054	·0015
	20	·006	·0015	72	·0255	·0015	124	·0365	·0015	176	·0555	·0015
	24	·0075	·0015	76	·027	·0015	128	·0375	·0015	180	·057	·002
	28	·009	·0015	80	·0285	·0015	132	·039	·0015	184	·059	·002
	32	·0105	·0015	84	·030	·0015	136	·0405	·0015	188	·061	·002
	36	·012	·0015	88	·0315	·0015	140	·042	·0015	192	·063	
	40	·0135	·0015	92	·033	·0015	144	·0435	·0015	196	Broke.	
	44	·015	·0015	96	·0345	·002′	148	·045	·0015			
Weight, 22 lbs. 12 oz.	48	·0165	·0015	100	·0365	·001′	152	·0465	·0015			
	52	·018	·0015	104	·0375	·0015	156	·048	·0015			

DESCRIPTION OF THE PLATES.

PLATE X.

Is the testing machine in which the experiments were made. Fig. 1 is a front elevation; Fig. 2, an end elevation or profile; and Fig. 3, a plan of the machine. In all of which A is the bed upon which the tested beam rests, and to which all the apparatus for applying the straining force as well as indicating its effects are fixed; B, B, are two standards or brackets bolted securely to the flooring or other convenient fixing; C, is the main lever through which the force was applied to the beams, connected to the bed A by links DD, its mechanical advantage being 12 to 1; E, the index plate, graduated to 1000ths of an inch, and connected with the beam by the intervening lever F under the bed A and the adjusting rod G, the end of the lever F being connected to the axis of the index E by a fine silk thread, and its weight counterbalanced; H, a scale in which the weights were placed; KK, counterweights to relieve the machine of the effect of the lever and scale; L, a rope by which the load can be relieved at pleasure to ascertain the effect of the load upon the beam; M, the beam experimented upon.

PLATES XI. AND XII.

Contain the several beams used in the experiments; shewing the sections taken at the point of fracture; and the sections taken at the centre of the length of each specimen, or at the line AB. On comparing the position of the beams, as shewn by the sections, with the position as shewn by the section in the first column of the tabulated results, the peculiar circumstances of each experiment will be ascertained. The dark spots on the sections at the point of fracture, represent air bubbles or imperfections in the casting, and the dark lines across the beams the lines of fracture. The position of these, in some of the open beams, is very remarkable.

XII.—*On certain Forms of Locomotive Engines.* *By* Edward Woods.

Amongst the causes which contributed to the success of the earlier experiments in locomotion upon the Liverpool and Manchester Railway, the method of generating steam deserves the most prominent place. The chamber or fire-place, containing a large mass of fuel surrounded on every side by water, with its appendage of tubes, or small flues disposed in the interior of the boiler, and exposing a large surface to contact of the heated air, was well calculated to turn to good account whatever heat the fuel during its combustion might produce.

It is however by no means improbable that this ingenious contrivance would have failed in securing the end proposed, and would perhaps even have been abandoned, but for the judicious application of a discovery, then only recently made, the practicability of producing a strong artificial draught of air through the fire, with facility and economy, by the exhausting power of a jet of waste steam directed upwards into the chimney.

The powers of the arrangement as thus combined, were attested by a very rapid generation of steam, and by the consequent attainment of a speed of travelling nearly threefold greater than any previous system had accomplished.

It is therefore less a matter for surprise that few attempts should have been made to improve upon so simple and effective a form of boiler, whilst material variations were taking place in the outward plan and disposition of the machinery.

Under the hands of different builders of locomotive engines for railways, the boilers have been subject to various slight modifications; but, whether fire boxes have been constructed of iron or of copper, whether square with stays, or round without stays, whether the tubes have been more or less in number, of larger or smaller size, or of different material, the combination of both, as it existed in the earliest engines, has been adopted on every line of railway where the transport of passengers is a primary object.

The case has been otherwise with the machinery destined to render available the resources which the boiler so abundantly provides; and builders, actuated by caprice and the desire of differing from competitors, or more laudably

influenced by the indications of experience, or by some happy effort of their own ingenuity, have departed widely from the first models submitted for their imitation.

Many crude schemes have successively appeared before the public, and have been deservedly rejected; many useful applications have withstood the test of time, and remained embodied in the machines to whose utility they have subserved. But although practical and scientific men are as equally agreed in condemning some inventions, as they are in approving others, there exists a class of forms, respecting the individuals of which, a great and reasonable difference of opinion is still entertained.

It is proposed in the present paper to state, with regard to a few of such forms, some results which the working of the Liverpool and Manchester line has afforded, and to consider what general arrangements of the parts of the locomotive engine are most conducive to its efficiency and durability, under the requirements of a railway intended for the transport of heavy loads at high speeds. The leading features into which a discussion upon the subject may with propriety resolve itself, bear reference to the relative superiority of—

Engines with four and with six wheels;

Engines with inside and with outside framings;

Engines with crank axles and with outside crank pins;

Engines coupled and uncoupled; and the forms arising out of different combinations of these with each other.

ENGINES WITH FOUR OR WITH SIX WHEELS AND INSIDE OR OUTSIDE FRAMINGS.

The engines at first introduced upon the Liverpool and Manchester line of railway were found to be much too slightly constructed for sustaining the shocks and strains to which their high velocities, and the inequalities of the road, continually exposed them; so that after a service short in its duration, but actually and unexpectedly great in respect of the distances travelled, each individual engine required and underwent a thorough and general repair. The nature of such repair consisted principally, at least as far as mechanical causes contributed to deteriorate the machine, in the substitution of greater strength and more approved forms of material, with a disposition and mode of connection of the parts, better adapted to resist frequently repeated and periodical concussions.

Thus the outer and inner framings were stayed in various directions; wooden wheels were replaced with iron ones; crank axles were constructed with almost double the original quantity of material; pistons, piston-rods, connecting rods and brasses were proportionally strengthened, until, finally, little remained of the old engine but its boiler and cylinders.

Such extensive alterations naturally occasioned a considerable addition to the weight, and it was found accordingly, that the engines first operated upon, built after the form of the "Rocket," and originally weighing from four and a half to five tons, became at least two tons and a half heavier than before; whilst others subsequently introduced, and known under the denomination of the "Planet" class, were increased in nearly the same proportion, arriving ultimately at no less than ten tons.

However conducive to the durability of the engine these alterations might prove, the effect of greater weight moving upon the road, could not be otherwise than highly prejudicial. The road was in fact formed of rails intended to support a moving mass of not exceeding four tons and a half distributed upon four wheels.

Indeed the terms prescribed in the competition for the premium publicly offered in 1829, shortly before the opening of the railway, required of the builder or inventor who proposed to submit his engine for trial, that it should be supported upon not less than *six* wheels, if the weight exceeded *four and a half*, or fell short of *six* tons; six tons, inclusive of the complement of coke and water, being the extreme limit allowable.

It was soon found impracticable to maintain the road in a state of efficient repair, when subjected to the influence of such disproportionate weights, rolling at great speeds, and frequently acting with the full force of impact due to the velocity of descending deflected portions of the rails. The rails were seriously bent, continually becoming loose in their supports, and frequently broken.

To return to the lighter form of engine, had it been even practicable, would not have been desirable; the only alternative that remained, and of which the adoption was ultimately decided upon, being to relay the whole line with stronger rails, and in the mean time to apply precautionary measures to lessen the evils adverted to. Such measures were rendered indispensably necessary by the arrival of some engines of still greater weight than any before in operation.

The most obvious remedies were: first, to place temporary props under the rails between the points of support, and more especially near the ends of the rails; and secondly, to add a third pair of wheels to the hind part of the framing of the engine. Both these expedients were extensively resorted to. The "Mars" and the "Atlas" first underwent the alteration, followed by the "Titan," "Orion," Hercules," Thunderer," "Firefly," "Planet," and others, engines originally provided with only four wheels.

In the structure of engines which have cylinders within the framing, and consequently inside cranks, it is a necessary condition that the centre of the main or crank axle should be placed in a position to allow the crank and connecting rod ends to clear the front of the fire-box during their revolution. This circumstance evidently limits the distance from the crank axle to the centre of gravity, and causes considerably more than half the weight to rest upon this axle, inasmuch as the fire-box, with double casing, fuel, bars, &c., constituting by far the heaviest proportion of the engine within a given length, completely overhangs its centre.

From hence has resulted, during the rapid transit of engines upon an uneven surface, (and no railway has yet been constructed free from inequalities,) a continual vibratory motion in a plane perpendicular to the direction of the axles.

Now as the effect of any downward motion in the vertical plane, or in other words, the amount of injury sustained reciprocally by the engine and the road, is expressed by the velocity which the centre of gravity has acquired in vertical descent, multiplied by the weight of the body, so most injury is received when the wheels of the large axle pass the obstacle, because for any given amount of their depression or elevation, the centre of gravity falls or rises through a greater space. The more equally we can divide the centre of gravity between the bearing lines, and the larger the interval between those lines, the greater becomes the steadiness of the machine. Considerations of this nature are necessarily influenced by the general form and dimensions of the parts to be acted upon.

The established form of the locomotive engine did not so much admit of alteration as of addition, and accordingly the third pair of wheels was placed behind the fire-box, to aid in its support.

The advantages obtained were almost immediately apparent. The engine lost in a great degree its peculiar rocking motion, as also the unsteadiness arising from lateral undulations; which latter effect was in like manner

attributable to the diminution of the angle of which the oscillations were susceptible. Beside such direct and immediate results, time soon developed further consequences of an important nature. The component parts of the engine remained for a much longer period than before securely united and firm, the fastenings of the tubes became less liable to leak and give way, and the bolts and stays of the framings were less disturbed. Lastly, though not of least importance, an inherent source of safety was superadded, in the diminished liability of the engine to run off the rails in the event of the large wheels or the crank axle breaking. Instances in which this quality has been put to the proof have occasionally occurred. They have invariably demonstrated the high importance of the application as an especial security to passengers and to the attendants; and in consequence the principle introduced was not abandoned, even after the road had been entirely relaid with new rails.

Inside and outside framing.

Intimately connected with the safety of railway travelling, and with the mode in which the application of six wheels can be turned to best account, is the often agitated question of an outside framing. It cannot admit of doubt in the mind of any one at all conversant with the properties of machinery, that an axle or shaft impelled by any given power will revolve more steadily, in proportion as the distance is greater between the bearings, provided at the same time, its form be of strength sufficient to resist deflection. No bearings can be made, or if made, could long continue in strict mathematical adjustment with the axis of motion. Where the power is uniform and acting only from one direction, as in the case of a wheel and axle driven by a strap, or by another wheel, a slight deviation from truth is of comparatively small importance, and in fact occasions no perceptible amount of eccentricity in the motion; but when the impelling power is variable in its action, and not only variable but applied alternately to opposite sides of the axis, the wear of bearings proceeds in a two-fold direction, and the want of accuracy becomes detrimental to the machine. Were the power (supposed acting periodically on both sides of the axle) constant in its nature, in so far as that at the same moment it only impelled the same side, the axle would simply roll to and fro in its bearings during such period, accompanied indeed by a slight shock at the moment of reversal, but preserving throughout its parallelism. The case with the locomotive engine is in this respect different. The axle with its double crank is urged by two independent forces, not operating simultaneously but periodically, opposed to each other; and the consequence ensues, that the axle, the wheels, and

finally the engine itself, is thrown into a state of vibration, the angle of which is precisely in the inverse ratio of the distances between the bearings. Hence those engines whose bearings are only about four feet asunder, soon acquire play in the brasses, and unless frequently examined and repaired, become unsteady and even unsafe when travelling at rapid speeds.

This consideration (one as I conceive of great importance) does not immediately involve the principle of an outside framing, inasmuch as greater length of axle may be obtained by widening the road, but it has an indirect reference, when the contiguity of bearings is found objectionable, and the width of the way does not admit of alteration. The superior danger of the inside above the outside framed engine, consists in the fact, that should the wheel of the former become loose, or the axle break, the engine would almost inevitably fall over on its side ; whereas in the other form of engine placed under similar circumstances, the wheel remains confined within the framing, tending to support the whole, until the attendants shall have been able to arrest the further progress of the train. The application of the outside framing is attended with another advantage, of which the beneficial effects are exhibited in imparting, when properly constructed, a degree of elasticity to the whole machine, tending to equalize and reduce the injurious effect of concussions received during motion upon an uneven plane.

Objections to six wheels.

The principal objections that have been urged against six wheels are :—

1st. That they have less adhesion than four-wheeled engines.

2d. That the axle and the weight of wheels adds to the resistance, and consequently detracts from the available power.

3d. That they cannot traverse curves without increased strain and friction.

I shall offer some observations, seriatim, upon these objections.

With regard to the first, it is perfectly true that the adhesion is less ; for adhesion is proportional to pressure or weight, and the same weight supported on four wheels must exert a greater pressure per wheel than when it rests upon six ; but the real question to be considered, is, whether the *ratio* between the adhesion and the power* of the engine is not such as to permit the exertion of that full power in ordinary states of the railway and under the practical conditions of the traffic. Observations on the working of the Liverpool and Manchester line since the introduction of six wheels, have convinced me of the present sufficiency of adhesion. On referring to the weekly returns of the

"late arrivals of coach trains," with their causes, during the year 1837, the following particulars have been extracted of all delays alleged to have arisen from the slipping of the engine wheels. The account stands thus:

		Minutes.
In 3640	coach trains (first and second class) despatched from Liverpool to Manchester, the delays by slipping have amounted altogether to	412
In 3640	coach trains despatched from Manchester to Liverpool, the delays by slipping have amounted altogether to	792
7280	Trains delayed.	1204

Averaging one-sixth of a minute for each train on its trip of thirty miles.

The greatest delays recorded are about 30 minutes, the least 3 minutes*; the trains consisting of six or seven carriages. The time of performing the trip is one hour and a half for a first class, and two hours for a second class train. As the trips are frequently performed in less time, it is but fair to conclude that the actual loss of time by slipping is considerably greater than what is here assigned. I should imagine the real amount to be at least double.

The cases in which trains suffer delay by slipping form, therefore, rather the exception than the rule the existing inconvenience might, however, be almost entirely removed by coupling the wheels.

The Liverpool and Manchester engines have undergone little alteration in the ratio of adhesion to power, the power having in most instances remained the same, the weight only being increased, and the surplus weight sustained on an extra support. Engines altogether new are seldom of less weight in proportion to their power than those of the older make, as the "Mars" and the

* It may excite surprise that the delays experienced in the trips from Manchester to Liverpool should exceed those of the trips in the contrary direction. The fact is accounted for by two circumstances, which in any state of the road tend to render the times unequal. The station at Liverpool, from whence the locomotives start, is higher than the terminus at Manchester by $43\frac{1}{2}$ feet. The trips from Liverpool are therefore performed on an average descent of $43\frac{1}{2}$ feet in 30 miles, and those from Manchester on an average ascent of $43\frac{1}{2}$ feet in the same distance. The latter will be thus found to require about 14 per cent. more power than the former for an equal load, or, in other words, the load of the engine is increased, and consequently the tendency to slip. The second circumstance alluded to is the prevalence of westerly winds during a great part of the year. These, by increasing the resistance to be overcome, occasion considerable detention in the aggregate of a year's work.

"Atlas."* The usual weight is about eleven tons and a half, and nearly thus divided:

	tons.	cwt.	qrs.
On the fore wheels	4	10	0
——— driving wheels	5	0	0
——— hind wheels	2	0	0
Total .	11	10	0

Some engines are found frequently more subject to slip than others, although the weights upon the driving wheels have been the same, and the construction in other respects identical. This is, without doubt, to be attributed to malformation of the springs, and want of due adjustment to the weights they have to support. Our engine builders are remiss in their attention to the subject, and the springs of most new engines have to be taken in pieces and remodelled before they can become thoroughly serviceable. Rapidity of recoil when the wheel passes an obstacle is the point to be aimed at.

To the second objection I do not attach much importance; the additional weight of a pair of wheels, axle, springs, and pedestals, does not exceed 12 cwt., and therefore on a liberal estimate cannot oppose greater resistance than ten or twelve pounds, equal to about $\frac{1}{200}$th of the whole tractive power of the engine, a quantity insignificant when put in competition with any real advantage gained. Some portion of the power of the four-wheeled engine must be expended in the oscillatory motion, as well as in overcoming the friction of flanges continually rubbing against the rail; and such portion would, I conceive, be found even to overbalance the extra resistance of a third pair of wheels.

The third objection, viz., the tendency to strain and the friction in passing round curves, and the difficulty of "taking the points," is prevented by the simple expedient of rendering the pedestals to the axle of the hind wheels very light and elastic, so that they will yield readily sidewise to an impression. For this purpose it is found better to use small wheels, say three feet in diameter, that the plates of the pedestals may be long, and the axles at a considerable distance

	tons.	cwt.	qrs.		tons.	cwt.	qr.		tons.	cwt.	qrs.	Increase. tons.	cwt.	qrs.
* Mars, originally	4	15	0	+	2	14	1	=	7	9	1	2	4	1
now								=	9	13	2			
Atlas, originally								=	8	11	2	3	3	3
now								=	11	15	1			

below the framing. These plates are in some instances carried up on one side only of the frame; the opposite plate is turned underneath, and the whole acquires more flexibility. Such precautions render uncoupled six-wheeled engines capable of traversing safely curves of eight chains radius, at a speed of from 6 to 8 miles an hour; an instance has occurred of a short curve of only four chains radius being passed at a slow speed. The common plan of allowing play in the axle journals to meet the difficulty of passing curves, appears to be rather prejudicial than otherwise.

The application of the principle of elasticity should not stop at the hind wheels, but be in fact extended, though in a less degree, to the entire framing. In every railway, *lateral* as well as vertical inequalities exist, which continually drive the engine out of the straight line. The framing, if made pliant and yielding to lateral impulse, will be found to bend slightly, without disturbing the whole mass. The provision is, in fact, tantamount to a secondary and subordinate system of springs, and the engine as well as the road are less deranged, whilst at the same time an increase of available power is obtained, and the speeds are consequently faster.

Engines possessing only inside framings are evidently unsusceptible of lateral elasticity. Such framings are required, not merely to serve as carriages for the *boiler*, but likewise to sustain many parts of the machinery, a condition absolutely requiring inflexibility. Outside framings act simply as carriages to the boiler, and have no fixed connection with any other part. The machinery in these is attached exclusively to the *boiler*, and is less exposed in that position to casual jolts and strains.

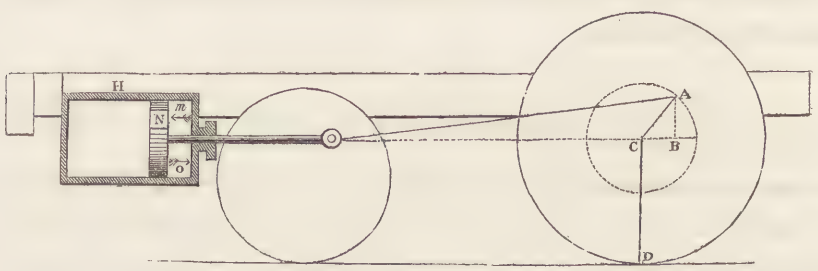
ENGINES WITH CRANK AXLES AND WITH OUTSIDE CRANK PINS.

The expense attending the construction of a crank axle, and its liability to fracture unless made with great care and of the best materials, have induced some builders to prefer a form of engine in which the large wheels are propelled by means of crank pins outside the wheels, and admit of being fastened on to a straight axle. The crank axle is thus dispensed with; the machinery is removed from under the boiler, and is consequently more accessible for examination and repairs; the boiler can be placed lower, rendering thereby the centre of gravity lower; and the large axle can be brought several inches nearer the

fire-box. These advantages are of importance when they can be obtained without prejudice to the combined actions of the machine. In the present instance such is unfortunately not the case.

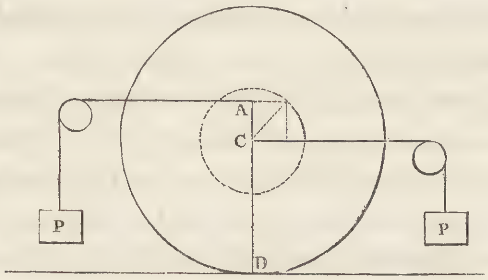
When the same shaft is impelled by two separate pistons, it is usual, and indeed it is most conducive to uniform motion, to place the crank pins at right angles to each other; that whilst one crank is "passing the centres," the other may be in full action. Hence, in engines worked by outside crank pins on the driving wheels, it occurs that at certain periods of the stroke, one *side* of the engine is impelled with the full force of one cylinder, whilst the opposite side has ceased to be impelled by the other; that in fact the line of pull does not coincide with the line of direction in which the centre of gravity of the engine is moving, but alternately passes from one side of it to the other during every revolution of the working wheels. This variation induces an eel-like side motion, and causes the flanges of the wheels to strike against the rails, and of course increases the friction. Such action has been always observed in engines of this construction, and is most injurious at high speeds. Being dependent on well-known mechanical principles, the amount of the forces producing it may be ascertained.

In the following Figure, H represents the cylinder attached to the boiler or framing; N the piston; CD the radius of the working wheel; AC the crank arm; AB the sine of the angle made by the crank in moving from the *horizontal* position.



Let steam be admitted behind the piston. Then, as the pressure is equal in every direction, the piston N and the cylinder H are pressed in *contrary* directions with exactly equal forces. Now if the piston be pressed in the direction of the arrow *m*, with a force P, the pin A of the crank must be pressed

in the *same* direction with the *same* force*; and again, if the cylinder be pressed in the direction of the arrow *o*, with a force P, the framing of the engine, the pedestals of the axle, and, in fine, the *centre* of the axle, must be pressed in the *same* direction and with the *same* force. Consequently, it is only by a difference of effect in these two opposite forces, in virtue of a difference of leverage, that any load can be drawn or any motion ensue. Whatever the forces may be, weights may be taken to represent them, and equivalent to them. Therefore to the point A of the lever AD (of which D is the fulcrum) apply the weight P, and to the point C of the same lever apply the weight P.



This arrangement will represent the relation of the two forces. If AC (the sine of the angle) have any value, motion must result *towards* the weight acting upon the longer arm of the lever, and the force producing motion must be equal to the extra weight required to be attached to C to restore the equilibrium.

Let this weight . . . . $= x$

the semidiameter (CD) of the working wheel . . . . $= d$

And the angle through which the crank has moved from the horizontal line . . . . $= \theta$

Then, in the case of an equilibrium, the radius of the crank being unity, we have

$$P. \{d + \sin \theta\} = d. \{P + x\}$$

$$\text{and therefore } x = P. \frac{\sin \theta}{d}.$$

In like manner it may be shewn that this is also the expression for the

* The consideration of the inclination of the connecting rod, arising from its limited length, as affecting the force transmitted to the crank, is not here entered into, as it would introduce complexity without sensibly influencing the result.

impelling force when steam is admitted into the opposite end of the cylinder; for then

$$\text{P}.\ \{d-\sin\theta\}=d.\ \{\text{P}-x\}$$

$$\text{and therefore } x=\text{P}.\ \frac{\sin\theta}{d}, \text{ as before,}$$

the force acting upon the *cylinder* having in this case the ascendancy.

Hence it follows, that the part of the engine to which the cylinder is attached, is urged forwards by a force (always represented by the expression $\text{P}.\frac{\sin\theta}{d}$) acting in a line which passes through the centre of the piston-rod, and affecting that part in a way precisely similar to what would have resulted, had an equal but *independent* force been applied from *without*. For it is clear that the extra weight or force x acts in the vertical plane in which the centre lines of the piston rod, connecting rod, and crank pin are situate. If this plane coincide with that which passes through the line of direction of the centre of gravity, a direct impulse will be given to the engine, and no tendency will exist to disturb the equilibria of the parts adjacent to either side of that plane. But should the two planes *not* coincide, a disturbance will take place, greater or less according to the magnitude of the interval which separates them. This disturbance would, however, be counteracted, and the equilibrium restored, by applying on the *opposite* side of the central plane, at an equal distance, an equal force. A locomotive engine provided with cranks at right angles, is impelled by two separate forces, acting at *equal distances* from the central plane. But these two forces, although equal to each other in the aggregate effect produced during one revolution of the crank, are by no means equal during every instant of the time in which the revolution is performed. They are, in fact, very dissimilar; and it is, therefore, by their difference at any given moment that the engine is urged to move out of the right line. The force impelling one side of the engine has been shown to be

$$\text{P}.\frac{\sin\theta}{d}, \text{ or } \frac{\text{P}}{d}.\ \sin\theta.$$

in which expression it will be observed that P and d are constant, $\sin\theta$ being alone variable; and that consequently the forces acting upon the sides, are respectively as the sines of the angles, and their *difference* equal to the difference of the sines multiplied by $\frac{\text{P}}{d}$.

For instance, put $P = 5000$ lbs.

$d = 3$ (the radius of crank being equal to unity).

Then $\frac{P}{d} = 1666$ lbs., which, multiplied by the difference of the sines, gives the *excess* of force by which one side is impelled above the other. Assuming the crank arm on the right side of the engine to be 90° in advance of that on the left, we perceive that, during one revolution of the axle, the force upon the *right* side has been twice equal to zero, whilst that upon the left has been at a maximum, or 1666 lbs., and that the force upon the *left* side has been twice equal to zero, whilst that upon the right side has been at a maximum.

It remains to explain what amount of side pressure is conveyed to the wheels under these circumstances. For this purpose it may be first assumed that the engine is placed upon a perfectly level plane, and is free to move sidewise without friction.

Let $W =$ the tractive power exerted.

$a =$ the force given out by one cylinder at some assigned moment.

$a + b =$ the force given out by the other cylinder at the same moment.

$r =$ the distance between the central plane and the plane which passes through the axis of the cylinder, piston rod, &c., (both planes being vertical and parallel to each other.)

$s =$ distance from the centre of gravity to the hind axle.

$s' =$ ditto from ditto to the fore axle.

Then, in the case of an equilibrium, we have

$$W = a + a + b.$$

a and a being equal, and acting at equal distances from the central plane, will not tend to produce side motion; the unbalanced force b will alone have that effect, and will cause the engine to turn about its centre of gravity. Let this tendency to turn be resisted by a force w, applied at right angles to the engine at a point opposite the centre of the hind axle; and by a force w', applied in a similar manner, but on the other side, at a point opposite the centre of the fore axle. Then when there is an equilibrium,

$$b.r = w.s + w'.s';$$

$$\text{also, } w's' = ws;$$

$$\text{therefore, } br = 2ws,$$

whence, $$w = \tfrac{1}{2} \cdot \frac{br}{s}$$

$$w' = \tfrac{1}{2} \cdot \frac{br}{s'}.$$

Suppose $b = 1666$ lbs.; $r = 3$ feet; $s = 1$ foot; $s' = 5$ feet; then w, or the side pressure upon the hind wheel, is 2499 lbs.; and w', or the side pressure upon the fore wheel, is 499 lbs.

The side pressure is resisted by the adhesion existing between the surfaces of the rail and wheel by the conical shape usually given to the tire, but especially by the flanges of the wheels. As in practice it is necessary to allow of some play between the flange and the side of the rail, a prejudicial swinging motion must arise. The nearer the cranks are brought to the centre of the engine, the more steady will its motion become; and when the line of application of the power coincides with the vertical plane of the centre of gravity, (as would be the case were the crank in the middle of the axle,) the force producing side motion altogether disappears.

On these grounds, outside cranks are undesirable, not only as tending, by the irregular motion they produce, to injure the wheels and axles, and to oppose considerable resistance to forward motion, but also as likely to prove injurious to the road. But outside cranks, in themselves objectionable, involve outside cylinders, and thence arises another reason for their rejection. Serious inconvenience must frequently arise from having the cylinders so directly exposed to the shocks and blows which their external position in the framing renders them liable to receive. In cases of serious collision, the front part of the framing is often broken. When the cylinders are inside, they are protected and sustain little or no damage. With outside cylinders the consequences have been more disastrous. The cylinders have been broken, and the adjustments of the machinery disturbed, to a degree which has required much time and labour to repair. To withstand the strains produced by the reciprocating action of the pistons, and the minor blows of daily occurrence, a strength of framing much greater than that of any inside cylinder engine is found necessary.

COUPLED AND UNCOUPLED ENGINES.

The unfounded apprehension entertained at an earlier, though comparatively recent, period in the history of locomotion, that engines would be unable to advance with any considerable load, without some mechanical contrivance for promoting adhesion or resistance between the wheel and the rail, has now been removed; the simple force of adhesion between the clean surfaces of iron having been found sufficient to resist the power applied to the driving wheels for effecting forward motion.

The force of adhesion, when the surfaces are in a clean state, (either thoroughly wet or thoroughly dry,) equals at least one-fifth of the insistent pressure. Under such circumstances, an engine, the weight upon whose driving wheels is *five tons*, would exert a tractive power of *one ton*, or 2240 lbs. without slipping; in other words, would draw a load of 250 tons upon a level railway. A favourable state of the road is, however, far from being constantly obtainable. In a damp atmosphere the rails are often partially wet without sufficient moisture to wash them clean, and the adhesion may be reduced from one fifth to one twenty-fifth of the insistent weight, and the engine may become unable to advance without slipping, with a load equal to more than one fifth of what may be considered its maximum. The usual load of a passenger train on the Liverpool and Manchester line seldom amounts to more than one third or one fourth of what the engine is able to draw at a slow speed upon any portion of the road; (with the exception of the incline of 1 in 96;) the power, as estimated *merely* by the dimensions of the cylinder, crank, and wheels, and by the full pressure of steam being three or four times greater than the resistance to be overcome. The question of *speed* bears no reference to the power thus considered, being solely dependent upon the *rate* at which steam of the required elasticity is generated. The adhesion, therefore, does not often prove less than sufficient for such trains, and it is on this account that the delays of passenger trains by the slipping of the engine-wheels are comparatively trifling. Upon railways whose gradients are less favourable, or the loads heavier, the inconvenience from slipping may be expected to be increased. The application of a convenient and safe method of coupling would in these cases be very desirable.

In the transport of merchandize, the difference between a speed of 16 and 25

miles per hour is not of much object, and the slower rate is adopted as being on every account more economical. The engine being now able to take a heavier load, obviously and indispensably requires more adhesion. Luggage engines, and those that assist at the inclined planes, have therefore been provided with the means of coupling the wheels, or of rendering the whole (or nearly the whole) weight of the engine available in producing adhesion. For this purpose, the fore wheels and the driving wheels are made of equal diameter, and both pairs are so united by outside connecting rods that the one cannot turn independently of the other. This arrangement is simple, and on the whole very effective, but is nevertheless open to objections, which especially render its application to passenger engines unsafe.

1. There arises frequently great extra friction from strains, occasioned by unequal wearing of the wheel tires, and from want of proper adjustments in the connecting rods.

2. There is considerable difficulty in passing round sharp curves.

3. There is risk of the connecting rods *breaking*. Such accidents are not of uncommon occurrence. Engines have been occasionally thrown off the rails by the end of the connecting rod striking the ground.

4. High speeds are very liable to derange the connecting rods, and are therefore unsafe.

5. A coupled engine *when it slips* is subject to a very violent side motion, and a great strain is thrown upon the wheels, the outside cranks, and the rods.

6. In a clean state of the road the connecting rods are not wanted, and only act as an incumbrance.

7. The fore wheels being of equal diameter with the driving wheels, the piston rod must work under the fore axle; the cylinders are then placed lower and in an inclined position. The *weight* of the fore wheels is likewise increased.

A mode of coupling, the invention of Mr. Melling, of this railway, has been applied successfully during the last year and a half upon the "Firefly" engine, which promises to remove the preceding objections, and is therefore peculiarly adapted to passenger engines. Whether this plan may as effectually prevent slipping as that now in common use, is a point which perhaps still remains to be decided; but that it is effective in a great degree cannot be denied. Having had occasion to make several experiments bearing upon the subject, I shall give a brief outline of the results.

The apparatus consists of a small independent wheel, which can be pressed

downwards, with considerable force, between the outer rims or tires of the driving and the fore wheels, and consequently can be made to transmit to the rim of the fore wheel the power given out at the rim of the driving wheel. The requisite force is obtained by opening a communication between the boiler and a small cylinder, the piston of which, with the assistance of suitable levers, is made to press the coupling wheels downwards.

Adhesion between the wheel and the rail is obviously proportional to the weight which exerts its pressure upon the two surfaces. When the rails are in a dry state, the weight upon the driving wheels produces adhesion sufficient to enable an engine to advance with a maximum load without slipping; but a slight greasy moisture diminishes the adhesion, and the wheels slip without advancing.

Under the last mentioned circumstances, the driving wheels alone of an uncoupled engine can slip, and no benefit would accrue from the weight sustained by the fore wheels. On the other hand, the driving wheels of an engine coupled with connecting rods cannot slip without at the same time causing the fore wheels to revolve. In this case the full benefit of the weight upon the fore wheels is obtained. It will, then, be evident that the method of coupling by a "contact" wheel, can only produce the extra adhesion in virtue of a transmission of the power from the driving wheel to the fore wheel, through the medium of the resistance opposed to the friction of iron *sliding* upon iron at the surface of the small coupling wheel. Such resistance, when the surfaces in contact are clean, is known to be very great, and would be sufficient to turn the fore wheels were they resting upon a slippery rail. But the greasiness of the rail is in some measure transferred to the wheel itself, and necessarily diminishes the adhesion of the coupling wheel. It might then be expected, that, whilst this wheel would in every case increase the total adhesion, it still would not exert a degree of power capable of overcoming the adhesion between the fore wheels and the rails. However, on reversing the engine suddenly, and applying the coupling wheel, I have frequently observed the fore wheels completely locked and sliding upon the rails. The following experiments were made with the view of ascertaining roughly, what difference in the amount of slipping the removal of the coupling wheel would produce, under equal conditions of load. The load assigned to the engine was that of pulling its tender with all the wheels locked. A slippery part of the road was chosen, and two stakes were there driven into the ground, 320 yards asunder. Proper counters were also

attached to the wheels for registering the number of revolutions. The engine being brought opposite to one of the stakes, the regulator was opened to its full extent.

EXPER. 1. Coupling wheel *in action.*
Large wheels made 92 revolutions.
Small ditto 87 ditto.

EXPER. 2. Coupling wheel *not in action.*
Large wheels made 136 revolutions.
Small ditto 87 ditto.

EXPER. 3. Coupling wheel *in action.*
Large wheels made 65 revolutions.
Small ditto 85 ditto.

EXPER. 4. Coupling wheel *not in action.*
Large wheels made 337 revolutions.
Small ditto 85 ditto.

Had the driving wheels not slipped, they would have made only 59 revolutions in the 320 yards; so that in the

1st	experiment	33	revolutions	were slipped.
2d	ditto	77	ditto	ditto.
3d	ditto	6	ditto	ditto.
4th	ditto	278	ditto	ditto.

The first and third experiments, being those in which the wheel was applied, are evidently the most favourable.

By this method wheels can be coupled whatever be their respective diameters, under the condition, which must obtain in every locomotive, of an equality of velocity in the revolving surfaces. The coupling wheel is under the entire control of the engine-man, and can be applied or removed at pleasure, without the necessity of stopping or even checking the motion of the engine. It is, however, subject to one mechanical imperfection. The tires of the engine wheels are conical, and therefore admit of connection only by the frustrum of a cone whose apex points in an opposite direction. Hence the outer edge of the tire iron revolves with a less velocity than the inner edge,

whilst the relative velocities of the outer and inner edges of the coupling wheel are precisely reversed. A perfect contact between the two surfaces throughout their entire width would occasion much friction by the sliding of the parts upon each other, and indeed would be otherwise objectionable on the ground of lessening adhesion, experience having well established the doctrine, that the narrower the bearing surface, the greater is the adhesion under equal pressures.

It became an interesting matter of inquiry to ascertain the amount of impeding friction produced by the full application of the coupling wheel, to determine what proportion of the useful effect of the engine would be absorbed. A set of experiments, conducted in different ways, viz. by the angle of friction, by the dynamometer, and by a maximum load, were carefully made. The results agreed very closely, and the mean obtained gave

120 lbs. as the absolute friction of the engine when *uncoupled;* and
200 lbs. as the absolute friction with the coupling wheel in full action.

The difference, 80 lbs., being due to the method of coupling. It may be observed, that 200 lbs. is scarcely less than the absolute friction of an engine coupled in the ordinary manner. When, however, we take into account the difficulties attending the adjustment of the connecting rods, whether in keying the brasses so accurately as to enable the cranks to pass the centres without strain; or in turning, and after they have been turned, preserving a precise equality in the diameters of the wheels, the conclusion at which we arrive does not seem premature, that on an average of circumstances the diminution of useful effect is less upon the system of coupling by contact, than upon that of coupling by connecting rods. If the rails be dry, the coupling wheel is lifted off and remains idle; but connecting rods *must* continue working, and then act only as an incumbrance. In damp weather only can the two modes come into competition. Whatever tendency to slip exists in the driving wheels must be transferred to the fore wheels. In the one case a constant pressure produces a constant resistance; in the other a variable resistance is occasioned by a friction of the joints of the connecting rods, increasing with every addition to the weight of the load.

EDWARD WOODS.

Manchester, Jan. 8, 1838.

XIII.—*Account and Description of Youghal Bridge, designed by Alexander Nimmo.* *By* JOHN E. JONES, *A.Inst.C.E.*

YOUGHAL, a town in the south of Ireland, county of Cork, celebrated as being the place in which the potato was first planted in Irish soil, by Sir Walter Raleigh, is a sea-port of considerable trade, situated on the river Blackwater, which separates it from the adjoining county of Waterford.

Until the building of the present bridge, a dangerous ferry of nearly half a mile was the only means of communication at this point between the two counties, except by going a distance of sixteen miles by the bridge of Lismore.

The erection of a bridge, which had been for many years in contemplation, was at length decided upon by the principal inhabitants of Youghal, and the late Mr. Nimmo, then employed as government engineer in Ireland, was applied to. He accordingly gave two designs, one for a suspension bridge at Rencrue, where the river narrows, the other, a timber one, within a mile of the town; the latter was preferred for many reasons, viz.: from its requiring an embankment to be made to low water mark, a distance of fifteen hundred feet, forming one side of a triangle, which, when completed, would enclose a tract of ground nearly four hundred acres in extent, and would also save much trouble and difficulty in forming the new line of road to join the old one leading from Waterford to Cork; but principally from its economy, there being ten thousand pounds difference in the estimates.

It was commenced in the year 1829 under my superintendence, and finished in the year 1832.

From the extreme length of the bridge and embankment, it has not been possible for me to give more than a perspective view of the entire structure in elevation, but I have made geometrical drawings of the different parts on an enlarged scale with a reduced ground plan. See Plates XIII. and XIV.

DESCRIPTION OF BRIDGE.

Its site is upon an arm of the sea, which forms the mouth of the river Blackwater, the rise and fall are sixteen feet each tide, the rapidity of the flow being so great as to increase one half its height in the first quarter.

There are two channels, east and west, separated by a bank of sand, the tail of which passes under the centre of the bridge and is scarcely covered at low water. The quay on the Waterford or western side is two hundred feet square, and its channel upwards of twenty feet deep at the lowest spring tides; from this circumstance it was considered the best place for the bascule, which was for the accommodation of the larger trading vessels, the smaller being enabled, like those on the Thames, to pass under by lowering their masts. The embankment on the eastern side is fifteen hundred feet in length. The face walls are built in good dry rubble work, varying in height from two to twenty feet, along which line there is a belting course laid in mortar, to support the parapet, which is four feet high and two feet thick, that next the sea having a curved batter of six inches to the foot; the upper face two inches to the foot; top of the wall is two feet six in breadth, with counterforts five by four and ten feet apart; the road is thirty feet broad, and there is a footpath on either side of six feet.

The foundation for the walls was formed by placing a heap of loose stones about six feet in depth along the entire line; upon this were deposited the materials for the future wall. This weight sunk the stones a considerable way into the sand. The filling was then thrown in, and the whole allowed to remain in that state for twelve months, during which time, if any part of it sank, there was more added, until it at last became one firm mass. The temporary walls were then taken down and rebuilt, according to the section given in the drawing.

The bridge unites with the embankment at low water mark, and is 1542 feet in length; it is composed of 47 bays of 30 feet span. The bascule and its piers 80 feet and 52 feet, the space occupied by the piles making the total length of timber work 1542 feet. Its breadth is 22 feet, and height above high water 10 feet, which makes a variation in the length of its piles from 36 to 70 feet; those I have drawn are the two extremes as far as the depth of the piles in the ground, but are shewn in 15 feet water.

The timber is of crown brand Memel, selected by one of the contractors who went there for that purpose. The beams were 14 inches square, and in length from 44 to 90 feet; the specification only required that the piles, caps, and all the larger timber, should be 12 inches square, but the contractors did not reduce it, though they were aware it would have paid very well for its sawing. Mr. Nimmo, in his specification, allowed the piles to be scarfed, which however

was not necessary, as long as the selected timber lasted, but from not having imported quite enough, they were obliged to have recourse to this method, not being able to get any of sufficient length in either Cork, Youghal, or Waterford. The quantity of timber used was nearly as follows:

	Tons.
Hand Railing	69
Flooring	220
Joists	164
Bolsters	30
Caps	26
Piles and in breakers	420
Struts and straining beams	105
High and low water gauge beams	60
Diagonal beams	38
Total number of Tons	1132

The dimensions of the gauge beams, diagonal braces, caps, bolsters, joists, struts, straining beams, purlin beams, and flooring, &c., &c., are given in the large elevations and sections.

The caps are fastened to the heads of the piles by an oaken coke three inches in diameter and six in length, through which an inch and quarter iron bolt is driven. At each side of the high water gauge beams, there is an iron strap three inches broad and half an inch thick thoroughly bolted. There are also three tailed straps at the joining of the struts and straining beams.

In the specification it was said the piles were to be driven ten feet at least, or until they did not move an inch after receiving twenty blows of an iron ram five cwt. falling ten feet; however, upon driving the piles which formed the first pier, I found that the bottom was so soft, that their own gravity sunk them five or six feet, and that it required very little additional power to drive them the remainder of the ten feet! Upon applying to Mr. Nimmo, he said his idea was, that ten feet would have been enough for the piles to go into the ground, and that it was only in cases where they would not go that depth that he specified otherwise. This circumstance, as well as my observing that the narrowing of the river by building the embankment on the eastern side had caused a washing away of the bottom, induced me to recommend the commissioners to pay an additional sum to the contractors for driving the piles as far

as they would go, which proved to be in many instances 25 feet. In cases where the ground was at all hard, the piles were shod with iron, as I have shewn.

The quay wall is four feet six at the top and twenty-six feet high, battering two inches to the foot, with counterforts four by eight, and ten feet apart.

There are two toll houses and about three miles of new road, which comprises all the works connected with this bridge.

The entire length is as follows:

	Feet.
Embankment	1500
Timber Work	1542
Quay Wall	200
Total . .	3242

The expense was under £18,000, but it could not have been done for anything like that sum, had it not been near one of the finest quarries in Ireland.

JOHN JONES, C.E.

London, June, 1837.

XIV.—*On the Evaporation of Water from Steam Boilers.* *By* JOSIAH PARKES, *M.Inst.C.E.*

THE Tables recorded in this paper contain the details of numerous experiments on the evaporation of water from three classes of steam boilers, and they are presented to the Institution in the hope that they will be found to satisfy, in some measure, the desire so generally felt by the members of the profession for well authenticated facts illustrative of the powers of coal in producing steam. The economy of fuel is the secret of the economy of the steam engine; it is the fountain of its power, the cause of its utility, and the adopted measure of its effects; whatever, therefore, conduces to increase the efficiency of coal, and to diminish the cost of its use, directly tends to augment the value of the steam engine, and to enlarge the field of its application. These sentiments, with the conviction that we are yet far from having attained either a complete knowledge of the most profitable manner of submitting coal to the process of combustion, or of applying the caloric so raised to the generation of steam, must form my excuse for offering the following remarks, partly explanatory of the Tables and partly relative to the state of our knowledge and practice.

Table I. The 1st Table, extracted from a paper of my own, (which is, I believe, the earliest on record,) appeared in the Quarterly Journal of Science and Arts for the year 1822, and exhibits the results of various experiments conducted on a large scale, at different establishments, with different varieties of coal, different sized boilers, and two very different modes of firing them. The rigorous accuracy of each experiment may be relied upon. During every one of them the party owning the boilers, or a confidential deputy, was present with myself to superintend the weighing of the coals, and the measurement of the water, the object being to prove or disprove the economy of a method of firing and burning smoke which I introduced. For a thorough understanding of this Table, and to facilitate a comprehension of all the phenomena and facts established or illustrated by it, it will be necessary that I advert to the origin of the experiments, and explain the purposes for which they were undertaken. By so doing alone can I render intelligible the phrases, *old* and *new* plans of firing, given in

the third column, and enable the consulters of the table to follow me in its analysis.

My mind was first attracted to the study of combustion, by the perusal of that inimitable account of an almost matchless discovery, viz., "Sir Humphry Davy on the Safety Lamp and on Flame." I then, for the first time, understood the laws which govern the ignition of the inflammable products of coal, as well as the nature and proportions of the several elements necessary to effect it.

It was, at that period, a desideratum at my father's works at Warwick that the smoke evolved from the engine chimney should be diminished, or if possible annihilated. This induced me to give my attention to the management of the engine and boilers, which had hitherto, as in most other establishments, been left to the nearly uncontrolled carelessness of the fireman. The furnaces had hopper mouthpieces, originally fixed by Messrs. Boulton and Watt, with a provision for admitting a thin stream of air into the fire, over the mouthpieces, in order to consume the smoke. This contrivance was of very little service, as volumes of smoke and soot were emitted from the chimney at each successive firing. I essayed heavier and less frequent firing, operating myself for many days together, that I might become expert in handling the shovel, at the same time regulating, with all the care I could, the admission of air over the hopper. Still I produced but little diminution of the nuisance. I frequently found the smoke increased by the admission of the air, and observed the pressure of steam to fall in consequence. I was perplexed, but the study of Davy at length furnished me with the clue for extricating myself from this labyrinth. I perceived that the conditions on which success depended were not fulfilled, and that failure was unavoidable; that the air must be given *directly* to the uninflamed gas, whereas it had become vitiated by passing over inflamed fuel; that it should be administered at the point of greatest heat, the temperature of incandescence, at least, being necessary for inflammation; whereas the air was admitted by the hoppers at the coolest part of the furnace. These considerations, with many others, led me to think that I should find the bridge of the furnace the most likely for combining the requisite conditions for solving the problem, and that by giving air there in due quantity, I should effect my purpose; that I should, at that place, encounter all the uninflamed as well as the inflamed gas, and obtain at all times the temperature necessary for ignition. I was not disappointed in these views, as the sequel will show, but I resolved to proceed

cautiously, in order to be able to estimate the resulting gain or loss, and before altering the furnaces, I determined to ascertain the duty done by the fuel measured by the evaporation of water.

I continued these experiments for some weeks, carefully noting down and registering every fact as it bore either on the furnace, boiler, or engine, till I had collected a sufficient number of facts to form a fair average of the value of a hundred weight of coals expressed in cubic feet of water evaporated. The engine was of 25 horses' power worked by two boilers, and so fully loaded that one boiler was insufficient for its supply. I, therefore, could not alter my furnaces until we could afford to stop the works for 2 or 3 days. In the meantime I entered upon another and perhaps more important set of experiments, viz., the proper treatment of the fuel, and the effects of different modes of firing the boilers. I had observed that less smoke was emitted from less frequent, than from very frequent firing, and I found that somewhat more water was evaporated in the former than in the latter case, by the same weight of fuel. There were also fewer cinders made, as there was less poking; the dampers were lower, as there was a greater mass, though less intensity of heat; and we were less plagued with scoriæ, as the temperature of combustion was less elevated. These first fruits, though not of a very decided character, led me still more and more to diminish the frequency of firing, until by degrees I arrived at a mode of working the engine with two charges of coal per diem; that is, the furnaces were loaded in the morning, as rapidly as keeping up the steam would permit, with sufficient coal to work the engine till dinner time. The grates were then cleaned, and charged again during the dinner hour, requiring no more fuel during the day.

I now found very marked results; economy of fuel, greater steadiness of steam, much less smoke, still fewer scoriæ; and I resolved, at the time of reconstructing the furnaces for giving air at the bridges, to enlarge the whole capacity of the furnaces, so that they might contain, at once, the entire of the fuel requisite for the day's consumption. This was done, and as the summit of the chimney was at that time undergoing repair, I had a convenient scaffold left, in order that I might, at my leisure, examine the temperature of the air at its exit, under the various novel experiments I was now prepared to make. At the same time I covered the boilers, hitherto uncovered, with double arches of brickwork, leaving an air space between each arch and the boiler, coating the outer arch thickly with strong hair mortar mixed with waste of wool. I

provided also for the more convenient measurement of the water entering the boilers, by dividing a rectangular reservoir which formed the roof of the boiler-house into two portions, the one of which was filling, whilst the other was emptying; so that I could tell, by the inspection of a gauge and scale, at any period of the day, the amount of evaporation. I also pierced holes for eye-pieces through the walls at the end of the boilers opposite the fire doors, to obtain a view of what might take place at the bridges, on opening or shutting the air valves; also eye-holes for the side flues, to ascertain how far flame extended.

My expectations were now in every respect realized. From about 7 o'clock in the morning no smoke was visible; it was under perfect control, as the inflammable gases could be ignited or be reduced again into smoke at will. The dampers, of which I had two to each boiler,—one self-acting by the steam but not shutting quite close, the other closing hermetically under the control of the fireman,—were very close down, and capable of keeping the steam so steady that it did not vary $\frac{1}{8}$th of an inch in height during many hours. The furnaces, when thus charged, may indeed be considered as great reservoirs of fuel in a constant, equable, but moderate state of combustion; not the entire mass on fire at once, but distilling first its gaseous products, then gradually entering into combustion according to the demands of the engine, made through its interpreter and agent the damper. At the dinner hour—as the load on the engine remained nearly undiminished to the last moment, and the steam consequently at the full working pressure—the dampers were closed, as nearly as was safe to avoid explosion in the flues *, and so much water was let into the boilers, as we knew by practice would be boiled, and allow the steam to rise to its point again at the starting time, the water having been allowed to waste in them as low as possible previous to stopping. At night the boilers were dosed with water in the same manner, which effected two little bits of economy

* If the dampers of a steam boiler are suddenly and closely shut, whilst the fire is in brisk activity, flame is extinguished, and the flues become filled with carburetted hydrogen gas. By the admission of a certain quantity of air, on re-opening the dampers, an explosive mixture is sometimes formed, and if its ignition should take place, which occasionally happens, the flue walls may be blown down. This evil is completely obviated by carrying up a small chimney through the boiler house, communicating at its lower end freely with the flue, and closed externally by a light sheet iron door hinged to a frame set flat on the top. A chimney 12 or 14 inches square will suffice to pass the explosion without injury to the walls of the boiler.

more; it prevented, by taking up the heat of the flues, &c., that blowing off and waste of steam which necessarily occurs at the moment of stopping, and is renewed frequently during the night; and on recommencing work in the morning, 2 or 3 hours elapsed before the boilers began to require water, which gave the fireman time to get on more rapidly with his charges, and diminished the demand for heat on starting the engine.

The method of charging the furnaces is as follows. The fireman commences getting up his steam about 5 o'clock, or an hour before the starting time in the morning, which is soon done, as well covered boilers lose little heat during the night from radiation. The steam up, he continues to throw on coals, thickening the mass towards the bridge, as quickly as combustion will permit, and a skilful hand will have about a third of the day's consumption of coals on the grates before starting his engine. The engine started, he soon finds he has an excess of steam; this is the signal for continuing the process of charging. With a rake he pushes backwards, towards the bridge, all the fuel he can without uncovering the bars, and pitches in fresh coals to the end of the furnace, occasionally ramming them up with his rake till they fill the space between the crown of the boiler and the bars. He thus proceeds, as the height of the steam will let him, till he has brought his charge home to the mouthpiece, ramming it all the way. The mouthpiece is then also filled full of well wetted slack, and if the nature of the coals permitted, I invariably found advantage from drenching them with water, as they coked better. The furnaces thus charged, the self-acting dampers—which were kept open during the whole process of charging—were set at liberty, and allowed to act freely. About 7 or 8 hours after the charge is made up on grates properly proportioned for this system of management, the coal towards the mouthpiece, with that in the mouthpiece, will require to be pushed backwards, to supply the waste at the farther end of the grate, and burn all up.

With respect to the smoke, a small quantity of air may be given shortly after the fire is made, and will be found to require a great increase for three or four hours after charging, when the greater portion of the gas uninflamed within the furnace will have passed over; the air valve may then be gradually closed, and finally be kept closed for some hours. It would be tedious to enter into an account of all the various phenomena connected with the ignition of the gaseous and carbonaceous matters at the bridge: suffice it to say, that with a rod brought from the air-valve to the eye hole, the admission of air could be so

regulated as to produce intense brightness, the character of perfect inflammation, or all the varying hues from blue to dull red, according to the varying circumstances and products of combustion in the furnace; and frequently, no flame would be visible, as there was no gas coming over.

From the foregoing description will be understood the meaning of the term *new*, as compared with the term *old* or common plan of firing used in the Tables.

It will not be supposed that I arrived all at once at perfection. It was not till after many trials and alterations, and much practice, that I attained an economy in regular work which I have never been able to surpass; nor have I ever reached quite the same amount at other establishments which I accomplished at my father's works, where I added a third and larger boiler, increasing the allowance of 5 square feet per horse power to $8\frac{1}{2}$. The 5 square feet per horse power, was the rule of Messrs. Boulton and Watt, reckoned on the surface of water in the boiler. It is evidently a very imperfect rule, and applicable only to boilers of one given form, whose surface exposed to the heat varies in a fixed ratio with the evaporating surface. The Lancashire engine makers commonly allow $7\frac{1}{2}$ square feet of water surface per horse power, and the employers of engines would do well to require and to use not less than 10 square feet per horse power *, if desirous of raising steam with economy. The evaporation which I obtained from 112 lbs. of coals at Warwick, averaged $18\frac{1}{2}$ cubic feet for six successive months, supposing the water to have entered the boilers at 212°, and including the coal used in raking the fires at night, and getting up the steam in the morning. This was accomplished with both Netherton and Newcastle coals, the Wednesbury giving somewhat less. When I tested the boilers originally, 12 cubic feet were the utmost I could evaporate, and the ultimate saving in money was fully two thirds, as with greater boiler power, larger grates, and slower combustion, we were able to use a cheaper description of coals, containing so much metallic and earthy matter that, on the plan of frequent firing, the fusion of these impurities took place, and the grates were choked with slag; whereas, with slow combustion, the incombustible portions of the coal simply remained on the bars, and did not

* Ten square feet of water surface of a common wagon shaped boiler, are equivalent to about 24 square feet exposed by the bottom, sides and ends, to absorb the heat, exclusive of a flue through the boiler.

materially interfere with the passage of air into the fire. I may also state that I have invariably found very narrow air spaces between the bars, and narrow bars preferable to wide spaces and wide bars—the grates being thus kept much cooler, and the residuum in the ash-pit rendered more worthless. Where the dimensions of boilers and grates are limited by circumstances, such as in marine and locomotive engines, these desiderata cannot perhaps be practically obtained, but the intense heat of the bars and ash-pits of those boilers, and the rapid destruction of the bars attest the injury and loss of heat, however unavoidable, which arise under such circumstances.

The experiments made on the summit of the chimney at Warwick were as follows. I suspended just within the orifice of the chimney, which was 65 feet in height, a copper kettle containing water which continually boiled, with the two boilers on the old plan of firing; but it rarely exceeded 180° with the three boilers on the new plan, and the average of the temperature, taken hourly throughout the day, was much less.

The evaporation of the water after the remodelling of the furnaces and covering the three boilers, rose from 12 to 15 cubic feet per 112 lbs. of coals on the old plan of firing, and reached $18\frac{1}{2}$ cubic feet on the new plan, as already stated, which will be found to be nearly one cubic foot more than is recorded at any of the establishments in the Table; but I have no doubt that I should have materially exceeded the maximum at Warwick, in several instances, had I been permitted to clothe the boilers, and to have applied and enforced the careful nursing and system of management which I was the master of at my father's works.

I subsequently took out a patent for the smoke burning process above described, and applied it to full 500 furnaces of various descriptions, introducing in every instance, and employing, as far as was consistent with the nature and object of the furnace, heavy firing and slow combustion, which was invariably accompanied with a greater or less degree of economy of fuel *.

* It may therefore fairly be asked, why a plan possessing, according to my statements, and according to the results of experiments authenticated by other persons of undeniable science and veracity, such decided advantages;—it may, I say, be fairly asked, why such a plan fell into disuse?

In reply to this question I shall again quote Davy. He came to see a boiler set and working perfectly on my system; he was much pleased, and not the less so on finding that he was the author of my knowledge, and he made me recount to him all my experiments. He frequently came to see

The interpretation of the laws of nature is more peculiarly the province of the natural philosopher; their application is the business of practical men: but, however great have been the labours and successes both of philosophers and engineers, in the science and employment of heat, much yet remains to be discovered by the one, and to be effected by the other, before we can realize in the steam engine all the powers of coal. We are still without any precise knowledge of the elementary fact, of the absolute quantity of measurable caloric contained in and obtainable from a pound of coal or other combustible; we are thus deprived of a datum or unit with which to compare our progress, and ascertain our distance from perfection, in the generation and employment of heat. We are also unfurnished with any definite determinate experiments regarding the proportions in which air and fuel unite during combustion; we are, practically speaking, altogether ignorant of the mutual relations which subsist between the combustible and the supporter of combustion; and though we know that without oxygen we cannot elicit heat from coal, we have yet to discover the most productive combinations of the two elements. Here then still remains a wide field for research and experiment, worthy and indeed requiring the labours of a profound chemist.

Experiments are also wanting to exhibit the relative heating powers, or calorific value of the solid and gaseous portions of coal.

The conditions to which steam boilers are subjected, and the laws which govern the ignition of inflammable matter, render it extremely difficult so

the furnace charged, and made experiments with the pyrometer on the temperature at the bridge, examined the gaseous products of combustion, &c. His approbation of the plan was not a little encouraging and flattering to a young man, but he one day said to me, "I believe you are right in pursuing this as a business, as you will gain much knowledge by it, which cannot fail to be useful to you; but you must not expect to establish it in general practice." I asked, "Why?" He replied, "It is too simple, and depends on the fireman and not on the master, who won't care to understand it, and who won't concern himself much about saving a few coals. You see that one half the miners won't even use my lamp, and persist in working comparatively without light, and in momentary danger of explosion and death, rather than adopt a new contrivance which insures them from both, but requires a small amount of trouble and care." His prediction was fulfilled; and for no other reasons which I could discover than those assigned; but still believing the system to be grounded on sound principles, I have thought that the details of the various experiments I have made on the subject, would find some value in the eyes of the Institution, many of whose members are specially interested in all that can throw light on the means of extracting from fuel the greatest possible amount of caloric.

to combine science and practice, as to avail ourselves of the full value of the gaseous products of coal. In all the intermediate varieties of coal from anthracite to cannel, the proportions of the carbonaceous to the gaseous matter contained in each, materially differ.

Anthracite has been termed native coke, and I have seen Scotch cannel giving out 85 per cent. of gas, thus nearly approaching the opposite extreme. Brilliant as is the Wigan cannel in a house fire, it inflames at so low a heat, and throws off its gas with such rapidity, that it becomes almost impossible to burn it alone with any effect, in a steam engine furnace, owing to the enormous quantity of air requisite for the inflammation of the gas. This last desideratum, viz., the calorific value of the solid and gaseous portions of coal, is capable of illustration by persons possessed of a small gas apparatus. The gas distilled from a certain weight of coal may be inflamed, and its value taken by the evaporation of water; the coke being afterwards burnt and tested in the same way. It would be sufficient to ascertain the value of the gas from a sample; the coal should be coked in a quantity sufficient for a day's use, and be burnt on the grate of a steam boiler, so as to compare it with the product of the same kind of coals, in the evaporation of water.

Experiments are also wanting on the relative heating powers of coal and coke generally. I have myself invariably found, as might be expected, that species of coal to be the strongest fuel, which contained the least gas, and vice versâ. I have also found that 75 lbs. of coke produced from 100 lbs. of coal, evaporated as much water as 100 lbs. of the self same coal. Such a fact would appear to be of a somewhat staggering nature, did we not know that the heat of combustion does not alone depend on the combustible, but also on the quantity of oxygen united with it, and the mutual action of those two bodies. I made the experiment with a view of confirming or disproving a similar statement, made I think either by Kirwan or Rumford.

It is not, I believe, common to find coal which will give 75 per cent. of perfectly well carbonized coke *. The coal which rendered me this produce, was the best St. Etienne of France, closely resembling in its character the best Newcastle. The power of coke, as fuel, is now become a very interesting subject of enquiry from its necessitated use in locomotive engines. The relative

* A valuable Table of the produce of coke from Newcastle coals, will be found in the First Volume of the Transactions, by W. Cubitt, V.P.Inst.C.E.

value of different cokes is speedily ascertained, and the best for their use adopted by railway engineers, but they can have no certain test of the excellencies of their boilers, as absorbers of heat, unless they note the evaporation. Would they furnish us with such facts, and would our marine engineers also communicate the results of similar experiments on steam boat boilers, we should soon be able to construct Tables which would exhibit, at one view, the comparative merits of every class of boiler, measured by their economy of fuel, under all the various circumstances of construction and practice.

By extracting the following Tables from the publications which record them, and by classifying and contrasting the facts which they severally exhibit, I have endeavoured to make known the present state of our knowledge on a subject which has been too little investigated, in the hope, also, that it may attract that attention which is due to its importance, and stimulate others to institute and communicate similar experiments. Evaporation experiments will determine the positive and relative value of different coals; they will prove the merits of different boilers; they will indicate the good or bad working condition of the boilers; they will detect the good or bad working condition of the engine itself; and their publication will stimulate those in charge of engines to a rivalry of care and skill, which cannot fail to produce economy in the use of fuel, and diminish the wear and tear to which all boilers and engines are subject. Experimenters should not fail to note the temperature of the feed water, nor to state the form and dimensions of their boilers and grates, with the exact measurement of the area exposed to the radiant and communicative heat. They should also particularize the nature of the coal, and the locality whence it is derived, with its cost to them.

TABLE I.

Place of Experiment.	No. of experiment.	Plan of firing.	Weight of water evaporated.	Weight of coals burnt.	Duration of experiment.		lbs. of water evaporated by 1 lb. of coal.	Cubic feet of water evaporated by 112 lbs. of coal.	Temperature of water on entering the boilers.	Weight of coals burnt to raise the water to 212°.	Weight of coals burnt in evaporation from 212°.	Observations on the boilers.	Water evaporated by 112 lbs. of coal from 212°.	Water evaporated by 1 lb. of coal from 212°.
	No.		lbs.	lbs.	ho.	min.	lbs.	Cubic ft.	°	lbs.	lbs.		Cubic ft.	lbs.
Messrs. Thomson, Chippendall, and Co., Primrose, near Clithero, Lancashire.	1	Old	12,956	2576	11	30	5·02	9	42	391	2185	Boiler 20 feet long × 5 ft. 6 in. wide, with a flue through it. Grates 3 ft. 10 in. wide × 4 ft. 6 in. long.	10·62	5·92
	2	New	14,356	2576	11	25	5·57	10	42	391	2185		11·77	6·55
	3	Ditto	9,318	1568	9	0	5·94	10·65	42	238	1330		12·55	6·99
	4	....	11,668	1568	10	0	7·44	13·45	44	235	1333	Same boiler reset, and grates enlarged to 4 ft. 6 in. square.	15·68	8·67
	5	New	16,775	2016	12	25	8·32	14·92	44	303	1713		17.54	9·78
Horrocks and Co., Preston, Lancashire.	6	Old	19,312	2576	9	19	7·5	13·4	76	322	2254	Boiler 13 ft. 6 in. × 8 ft. wide, flue through it. Grates 4 ft. 6 in. long × 6 ft. 2 in. broad.	15·35	8·59
	7	New	21,875	2576	10	0	8·48	15·2	80	314	2262		17·33	9·66
	8	Ditto	22,125	2638	8	0	8·23	14·75	74	341	2347		16·93	9·44
New River Head Waterworks, Islington. Newcastle coals.	9	Old	22,500	3200	10	59	7·03	12·63	102	332	2868	Two boilers, 15 ft. long × 5 ft. 6 in. broad, no flue. Grates 4 ft. × 2 ft. 10 in.	14·06	7·82
	10	Ditto	16,125	2312	8	0	6·97	12·5	101	241	2071		13·95	7·77
	11	New	15,375	1917	7	18	8·02	14·37	96	210	1707	Same boilers, grates enlarged to 4 ft. 6 in. square.	16·14	9·01
	12	Ditto	14,764	1837	6	54	8·03	14·4	97	198	1639		16·13	9·
	13	Ditto	18,112	2199	8	10	8·23	14·75	97	237	1962		16·51	9·21
Mean evaporation, old plan													13·49	7·52
Ditto ditto new „													15·61	8·70
Least ditto old „													10·62	5·92
Greatest ditto new „													17·54	9·78
Mean evaporation, at Warwick, new plan													18·50	10·32

OBSERVATIONS.

The experiments are stated in two modes, so far as regards the *temperature* of the water with which the boilers were supplied. The first expresses the real temperature of the water used during the experiment; the second exhibits the proportion of coal required to evaporate the water, supposing the latter to have entered the boiler at 212°. Another column shews the portion of coal

used to raise the water from its initial temperature to 212°. These latter columns are necessary, in order that the results of the several experiments may appear upon equal terms, as no just comparison can be made between them and others, unless the water, in all such experiments, be reduced to one standard temperature. In order to separate the weight of coal burnt in heating the water to 212°, from that actually spent in evaporating it, I have used Mr. Watt's figures for the latent heat of steam, and subjoin an example of the mode of converting the sums.

EXAMPLE. Vide Experiment 1. (Latent heat of steam 950°.—Watt.)

$212° - 42° = 170°$, amount of sensible heat required to raise the water from 42° to 212°.

$170° + 950° = 1120°$, the sum of the sensible and latent heat in steam generated from water of the temperature of 42°.

$\therefore 1120° : 2576$ lbs. coal $:: 170° : 391$ lbs. coal, burnt in heating the water from 42° to 212°.

$\therefore 1120° : 2576$ lbs. coal $:: 950° : 2185$ lbs. coal, burnt in evaporating the water from 212°.

The figures in the last two columns, which present the absolute result of each experiment, and the relative results of all, are obtained in a similar manner.

The weight of water evaporated in the first five experiments was ascertained by condensing the whole of the steam in a refrigeratory, used occasionally to supply the printing works with pure water. In all the other experiments the water was let into the boilers from a measured vessel, and the temperature of each dose noted. No one of the boilers forming the subject of the Table was clothed, yet it will be seen, that by resetting the boiler and grate used in the first five experiments, and by the more skilful management of the fuel, the product of 112 lbs. of coals, under the same boiler, was raised from 10·62 cubic feet to 17·54 cubic feet of water evaporated. This was one of 7 boilers set side by side and working together.

Mr. Thomson, the scientific owner, and myself afterwards entered on a series of experiments to determine accurately the amount of loss occasioned by the unclothed, or very imperfectly clothed state of all the steam pipes ramifying through his works, as well as the boilers; and we found that one of the 7 boilers was merely supplying the waste arising from the neglect of precautions, the wisdom and importance of which—however self-evident they may seem—

are, nevertheless, almost universally despised in practice excepting by the Cornish engineers.

Experiments 4 and 5 shew, as nearly as we could obtain, the value of the gaseous and carbonaceous matter which escaped in an unconsumed and unprofitable state, when no air was given at the bridge. In both experiments the grates were charged, but in the 4th the smoke was allowed to pass off unconsumed. In the 5th, the smoke was burnt, and the difference in favour of the last was $\frac{1}{8}$th, or $12\frac{1}{2}$ per cent.

Experiment 8, at Preston, was made to ascertain the greatest evaporating power of the boiler in use, which I considered to be the best set, and of the best proportions I had then seen, and possessing the finest draught. From these combined excellencies it exceeded the evaporating power of the boiler at Mr. Thomson's, which presented nearly the same area of heated surface, in the ratio of 2 to 1, and that without any material reduction in the effect derived from each pound of coal, as will be seen by Experiments 7 and 8. This excess in evaporative power is attributable, not only to the superiority of the draught of the chimney, but also to the greater width of the boiler, which permitted a larger quantity of coal to be brought into action, and presented a corresponding increase of surface to receive the direct radiant heat of the fire.

In all these experiments the water in the boilers was brought to the boiling point, and with as little ignited coal as possible on the grate, the experiment commenced.

Table II. The next Table is particularly interesting from the circumstance of its exhibiting the results of 8 monthly experiments of the whole water evaporated from the boilers working a Cornish pumping engine.

The particulars have been furnished me by the kindness of Mr. John Taylor, and are extracted from Captain Lean's monthly reports of duty, in which publication they will continue regularly to appear. These form the first of a series of facts, in ascertaining which the Cornish engineers have again taken the lead of all their brethren. They are second in importance only to the reports of the duty done by the engines, which have so materially accelerated the advance of the practical science of steam, and elevated the Cornish pumping engines to the very first rank in the scale of economy, when compared with any other of the numerous varieties of the steam engine. Similar experiments are now rendered easy to every one by the invention of a meter, through which all the water passes into the boilers, and is measured and

registered at the same time. This instrument owes its origin, I believe, to a prize offered by Mr. Taylor to the Polytechnic school, and he assured me that the Cornish engineers have full reliance on its accuracy. We may therefore anticipate the multiplication of these experiments, and the general adaptation of the instrument to the Cornish boilers; so that the monthly reports will contain not only a registry of the duty done, but also a registry of the fuel and water which furnish the power of the engine.

I have annexed to this Table two columns exhibiting the value of 112 lbs. of the coal in cubic feet of water from 96°, at which it entered the boilers, and 212°, by which a just comparison of these experiments can be made with those in the first Table. I have also added Mr. Henwood's experiment, extracted from his paper lately read before the Institution.

TABLE II.

Evaporation indicated by the Water Meter attached to the Boilers of Loam's Engine at the United Mines. Cylinder 85 inches, single. Coals 94 lbs. per bushel.

Time.	Duty done by the engine.	Consumption of coals in bushels.	Total water injected into the boilers.	Water evaporated by each bushel of coals.—Temperature of water 96°.		Water evaporated by 112 lbs. of coals from 96°.	Water evaporated by 112 lbs. of coals from 212°.	Water evaporated by 1 lb. of coals from 212°.
1837.	Million lbs.	Bushels.	Imperial gallons.	Gallons.	Cubic feet.	Cub. feet.	Cub. feet.	lbs.
March	64·9	3283	282,870	86·16	13·78			
April	64·5	2624	Counter idle.					
May 4th to 30th	68·96	2243	336,210	Boilers leaky.				
May 30th to July 4th	60·33	2555	268,500	105	16·80			
July 4th to August 3d	68·3	2090	204,190	97·7	15·63			
August 3d to September 1st	69·2	1973	254,275	128·8	20·62			
September 1st to October 3d	69·2	2117	210,130	98·3	15·72			
October 3d to November 2d	70·2	1897	177,135	93·3	14·92			
November 2d to December 1st.	70·13	1818	148,365	81·6	13·05			
December 1st to January 2d	74·12	No account.						
1838.								
January 2 to February 1st	70·37	2251	227,640	101·1	16·17			
Mean of all the experiments					15·83	18·86	21·16	11·80
Greatest ditto					20·62	24·56	27·55	15·37
Least ditto					13·05	15·54	17·33	9·67
Mr. Henwood's Experiment, Wheal Towan Engine. Coals 100 lbs. per bushel; water 93·8°; evaporation 16·95 cubic feet					......	......	21·31	11·87

OBSERVATIONS.

Some remarkable discrepancies appear between the returns of evaporation in this Table, there being no less than 50 per cent. of difference between the least and the greatest amount. Uninformed as I am of the circumstances which may have so materially influenced the monthly results, I can only point attention to the facts. Such irregularity cannot have escaped the notice of the superintending engineer, and is of itself a striking proof of the utility of the application of a tell-tale to boilers. I should accuse any fireman of mine of gross neglect, be led to investigate the state of the boilers as to cleanliness, &c., or search for other defects, did I ever find so great a fall as 10 per cent. below the maximum of evaporation *.

Table III. The next Table relates to the evaporative qualities of locomotive boilers.

M. de Pambour did not fail to analyse these important functions, nor to classify the results of his numerous experiments; but his object in noting the weight of coke burnt, and that of the water converted into steam, seems to have been with the view rather to establish the *evaporative power* of the different boilers, than to ascertain their respective and relative economy in the use of fuel. These facts are not, therefore, to be found side by side in his Work; they are registered in two distinct Tables (pages 175 and 320) †. I have extracted them from these two Tables, and now placed them in juxtaposition, in order that the value of this class of boiler, as an instrument of evaporation, may be found by comparing its performance with that of other boilers.

M. de Pambour has not stated the exact temperature of the water in the tenders, using only the loose terms "*cold,*" "*lukewarm,*" &c. I have, in consequence of this omission, been obliged to assume an average temperature, (which I have ventured to fix at 60°,) in order to construct the columns of evaporation

* Since writing the above, Mr. Taylor has informed me, that the irregularities in the monthly evaporation from these boilers, arise from the necessity of using mine water of a very bad quality—water which contains much free acid, with mineral solutions of a very deleterious nature. The boilers are also old, are obliged to be very frequently repaired and cleaned, and they are thus compelled for many days together to work the engine with only half its complement of boiler power.

† A Practical Treatise on Locomotive Engines upon Railways. By the Chev. F. M. G. de Pambour, 1836.

from 212°. The comparison with the other experiments would, however, still be imperfect, without due allowance being made for the superior strength of coke to that of coal. M. de Pambour particularizes the coke used as "Worsley coke of prime quality," a coke well known in Lancashire as the strongest and best for foundry purposes. I have, therefore, added other columns, reducing the power of coke to that of coal by the ratio of 10 to 8; in other words, assuming $\frac{8}{10}$ths of a pound of coke to be equal to 1 pound of coal. These last columns, therefore, are the standard of comparison with the other Tables.

These experiments appear to me to merit entire confidence as regards care in weighing, measuring, &c.; but yet there is a circumstance so commonly attendant on the working of a railway locomotive engine, that no experiments on evaporation can be considered as exact unless free from that error. I allude to the phenomenon of *priming;* a phrase used to express the passing over of water with the steam from the boilers into the cylinders, an effect very common, and arising partly from the rapid disengagement of the steam from so small a volume of water in so confined a vessel, and partly from the small capacity of the steam chamber. I do not mention this to throw the slightest discredit on M. de Pambour's experiments, but point it out as a precaution to be observed by all experimenters on locomotive boilers.

Table III.

Evaporation from Locomotive Boilers. By M. de Pambour.

Name of Engine.	Date of Experiment.	Consumption of coke.	Water evaporated in pounds.	Water evaporated in cubic feet.	Temperature of the water.	Pressure of steam in the boilers.	Evaporation by 112 lbs. of coke from 60°.	Evaporation by 112 lbs. of coke from 212°.	Evaporation by 89·6 lbs. of coke = 112 lbs. of coal from 212°.	Evaporation by $\frac{8}{10}$ lbs. of coke = 1 lb. of coal from 212°.
	1834.	lbs.	lbs.	Cub. feet.	Temperature.	lbs.	Cub. feet.	Cub. feet.	Cub. feet.	lbs.
Atlas	July 23d	1596	8260	132·16	Cold	53·7	9·27			
Ditto	Aug. 4th	1224	5937	94·99	Ditto	53	8·69			
Vulcan	July 22d	664	4646	74·34	Lukewarm	54·5	12·53			
Leeds.........	Aug. 15th	897	5989	95·82	Ditto	54	11·85			
Fury	July 24th	806	4878	78·05	Cold	57	7·94			
Ditto	Ditto	746	5446	87·14	Ditto	57	13·08			
Firefly	July 26th	879	6143	98·29	Almost cold	44	12·52			
Ditto	Ditto	870	6040	96·64	Lukewarm	44	12·44			
Vesta.........	Aug. 1st	774	4130	66·08	Very hot	51	9·56			
Mean of all the experiments							10·90	12·64	10·11	5·64
Greatest ditto							13·08	15·17	12·13	6·76
Least ditto							8·69	10	8	4·46

OBSERVATIONS.

The accuracy of these experiments derives further confirmation from three similar ones (reported by Mr. Wood in his Treatise on Railroads, page 412) performed on the Rocket, Arrow, and Phœnix, the mean of which is 10·08 cubic feet, evaporated by 112 lbs. of coke. Thus, it would appear, that though but little progress had been made in the *evaporative economy* of locomotive boilers between 1831 and 1834, their *evaporative power* had been increased from 36 cubic feet of water converted into steam per hour, the mean reported by Mr. Wood, to 55·82 cubic feet, the mean of M. de Pambour's experiments *.

The demand for power and speed in the locomotive engine has kept pace with the enlarged dimensions and better construction of the boilers; and probably the rage for velocity and heavier loads will, for some time to come, neutralize every effort of the locomotive builder to diminish the consumption of fuel; economy of time—the object of railroads—being diametrically opposed to economy of fuel, and economy of mechanical wear and tear.

Table IV. From the three foregoing Tables I have composed a fourth, which may be termed the comparative Table of results, shewing at one view the mean, greatest, and least evaporation, by 112 lbs. of coal in cubic feet of water at 212°. The Lancashire and London are taken from the figures, *Old Plan*, Table I.

Had we the knowledge of the relative strength of the coals employed, and full information of the respective areas of the heated surface of the boilers, an investigation into the *causes* of the superiority of one boiler over another, both as regards their *evaporative power* and *evaporative economy*, might be instructively if not successfully entered upon.

* In assigning to coke a superiority of $\frac{1}{5}$th in its heating power over coal, I believed myself to be within the mark. Mr. Apsley Pellatt has since communicated to the Institution the results of his extensive and valuable experience " on the relative heating powers of coke and coal in melting glass," by which it appears that London gas coke exceeded coals in calorific value 25 per cent. It is well known that all gas coke is very inferior to oven or *hard* coke, and M. de Pambour states the difference between the heating powers of these two sorts of coke in Lancashire to be $12\frac{1}{2}$ per cent. It would thus seem nearer the truth to diminish the evaporation from the locomotive boilers (in order to compare it with those using coals) by $\frac{1}{4}$th, or even $\frac{1}{3}$rd, rather than by $\frac{1}{5}$th, as in the Table.

TABLE IV.

Evaporation of Water from 212°, by 112 lbs. of Coal.

EXPERIMENTS.	Greatest.	Least.	Mean.	Authority.	Date of experiments.
	Cubic feet.	Cubic feet.	Cubic feet.		
Cornish	27·55	17·33	21·16	Lean.	1837
Ditto	......	......	21·31	Henwood.	1835
Warwick	......	......	18·50	Parkes.	1820
Lancashire.........	15·35	10·62	13·49	Ditto.	1821
London	14·06	13·95	14·0	Ditto.	1821
Locomotive	12·13	8	10·11	Pambour.	1834
Ditto	9·46	8·95	9·18	Wood.	1831

Table V. As an useful adjunct to the foregoing Tables I have composed another, shewing the proportionate parts of 112 lbs. of coal burnt in heating water from 32° to 212°, with that burnt in evaporating it from 212°.

It is constructed precisely according to the example given in the observations on Table I., and will be found to save considerable trouble in reducing the results of numerous experiments on evaporation to a common standard of comparison*. Required, for instance, to know the value of 112 lbs. of coal in evaporating water from 212°, which had converted 10·90 cubic feet into steam, from water at 60°. Vide 60° in the Table, and we have the formula;

$$10{\cdot}90 \text{ cubic feet} \times \frac{112 \text{ lbs.}}{96{\cdot}56} = 12{\cdot}64 \text{ cubic feet, evaporated from } 212°.$$

* It is very desirable, for many reasons, that all experimenters should reduce their results to one common standard; and though it may very rarely occur in practice that steam-boilers can be supplied with water at so elevated a temperature as 212°, yet that degree is evidently better suited for the purpose of a standard than 32°, the only other which could, philosophically speaking, be fixed upon.

TABLE V.

Temperature of the water.	Coals burnt in heating the water to 212°.	Coals burnt in evaporating the water from 212°.	Temperature of the water.	Coals burnt in heating the water to 212°.	Coals burnt in evaporating the water from 212°.	Temperature of the water.	Coals burnt in heating the water to 212°.	Coals burnt in evaporating the water from 212°.
°	lbs.	lbs.	°	lbs.	lbs.	°	lbs.	lbs.
32	17·84	94·16	94	12·37	99·63	154	6·44	105·56
34	17·67	94·33	96	12·18	99·82	156	6·23	105·77
36	17·50	94·50	98	12	100	158	6·02	105·98
38	17·33	94·67	100	11·81	100·19	160	5·81	106·19
40	17·16	94·84	102	11·62	100·38	162	5·6	106·4
42	17	95	104	11·43	100·57	164	5·38	106·62
44	16·83	95·17	106	11·24	100·76	166	5·17	106·83
46	16·65	95·35	108	11·05	100·95	168	4·95	107·05
48	16·48	95·52	110	10·85	101·15	170	4·74	107·26
50	16·31	95·69	112	10·66	101·34	172	4·52	107·48
52	16·14	95·86	114	10·47	101·53	174	4·30	107·70
54	15·97	96·03	116	10·27	101·73	176	4·08	107·92
56	15·79	96·21	118	10·08	101·92	178	3·86	108·14
58	15·62	96·38	120	9·87	102·13	180	3·64	108·36
60	15·44	96·56	122	9·69	102·31	182	3·42	108·58
62	15·27	96·73	124	9·49	102·51	184	3·20	108·80
64	15·09	96·91	126	9·29	102·71	186	2·98	109·02
66	14·91	97·09	128	9·09	102·91	188	2·75	109·25
68	14·74	97·26	130	8·89	103·11	190	2·53	109·47
70	14·56	97·44	132	8·70	103·30	192	2·30	109·70
72	14·38	97·62	134	8·49	103·51	194	2·08	109·92
74	14·20	97·80	136	8·29	103·71	196	1·85	110·15
76	14·02	97·98	138	8·09	103·91	198	1·62	110·38
78	13·84	98·16	140	7·89	104·11	200	1·39	110·61
80	13·66	98·34	142	7·68	104·32	202	1·16	110·84
82	13·48	98·52	144	7·48	104·52	204	0·93	111·07
84	13·29	98·71	146	7·27	104·73	206	0·70	111·30
86	13·11	98·89	148	7·06	104·94	208	0·46	111·54
88	12·93	99·07	150	6·86	105·14	210	0·23	111·77
90	12·74	99·26	152	6·65	105·35	212	——	112
92	12·56	99·44						

March 5th, 1838. JOSIAH PARKES.

XV.—*Account of a Machine for cleaning and deepening small Rivers, in use on the Little Stour River, Kent. By W. B. Hays, Grad.Inst.C.E.*

It is well known that the more rapid the current of a river is, the more effectually will it form and maintain for itself a deep and clear channel, because the friction of water moving rapidly is sufficient to remove such obstacles as mud, sand, or even fine gravel. The engineer who wishes to deepen a slow river, sometimes takes advantage of the knowledge of this fact, by using whatever means he can to increase its velocity. But if by any means advantage could be taken of the hydrostatic power of the water in a slow river, (the friction of which is small,) by arming it as it were with a set of scrapers, which should act upon the bed of the river to supply the place of this friction, the object would be obtained in less time, and more effectually, perhaps, than by increasing the velocity of the water.

Now the above advantage is taken in this machine. It consists of a boat having a broad rake or scraper attached to it, and propelled forward by the power of a head of water, which is constantly maintained behind it in the manner more fully described below.

Whether this principle would be applicable in rivers of any considerable size I am not able to say, but its success has been practically established in small rivers; that is, of a width of 50 or 60 feet, and depth of 5 or 6 feet.

This machine was contrived about 30 years ago by a gentleman of the name of Kingsford, a miller, at Seaton near Canterbury, the father of the present proprietor, and there are now, as far as I am aware of, only two machines of the same kind in existence. He was desirous of opening the navigation up to his mill for a length of 5 miles of a river which in some places was scarcely 12 inches deep, owing to the great accumulation of mud, &c.; and he effected his object almost wholly by this machine, which he then contrived for the purpose. Only in places where there was a more abundant accumulation of gravel a small hand dredging machine was used; indeed, the same boat was used for this purpose, by substituting a dredging apparatus for the rake and appendages used in scouring.

The machine has been constantly used on this river ever since, and with great success. They scour it out about once a year or two years as may be required. The bed of the river has been reduced about 4 feet below its original level, and is now maintained at that depth; this, besides benefiting the mill, (which was the immediate object,) has greatly improved the land, which was before a swamp, but is now very fine pasture.

I shall now proceed to give a brief description of the machine, with reference to the letters marked on the drawing. (Plate XV.) Fig. 1 is a side elevation, Fig. 2 an end elevation of the stern of the boat, shewing the rake without the "wings." Fig. 3 a plan. The same letters refer to the same parts in each view. The river in which this machine is used varies from about 20 feet to about 30 feet in width, and is about 4 or 5 feet deep. The rake A is a close wooden frame about 12 feet wide, shod along the bottom with iron spikes or scrapers, it is made of such a depth that when the scrapers touch the bottom of the river the top of the frame may be above the water. This rake has an apparatus of racks and pinions, pauls, &c., attached to it for the purpose of raising or depressing it; it is supported at the top by two slides, in which the pieces B, B work, and is held up to its work at the bottom by two chains C, C, one on each side of the boat. At each end of this rake is attached a close wooden frame called a "wing," E, these wings are of the same depth as the rake, at the ends at which they are attached to it, and are tapered off slightly towards the other ends, and rounded so as to fit the general slope of the banks of the river; they are attached to the rake by a moveable joint, so that when the machine is at work, they lie back against the banks on each side, and opening out where the river widens, or closing in where it gets narrower, they form at all times together with the rake a kind of dam to the water all across the river. The appendages of ropes attached to the pole D are for the purpose of drawing the wings up together to allow the water to pass when the machine is to be stopped.

In the operation of working this machine, they begin by pressing the rake firmly down on the bottom of the river, until a sufficient head of water accumulates behind it. The rake is then eased off a little, and the boat is pressed forward by the weight of water. The scrapers of the rake tearing up weeds, mud, &c., the whole is carried forward and eventually discharged at the mouth of the river. The wings and rake alone form but an imperfect dam to the water when the machine is first started, but when it gets an accumulation of matter, which it does to the extent of some hundred yards before it, the water cannot

pass so freely; and what little then escapes is rather an advantage than otherwise, as it stirs up the mud and keeps it afloat, so that it is more easily driven forward. In cleaning out a long river, it is necessary to do so in short lengths, perhaps a mile at a time, beginning nearest the mouth, because otherwise the machine would accumulate a greater mass than it could carry forward.

A head of water of from 6 to 12 inches is sufficient to propel the machine I am now describing; its speed varies according to the work it has to do, but never exceeds 3 miles per hour. The river in which it is used is 5 miles long, and takes 5 or 6 days to clean out.

I spoke above of another of these machines. It is used on the great Stour river, to which the little Stour is tributary. I advert to it, because it differs in some respect from the one I have been describing, on account of the river being larger, viz., from 30 to 60 feet wide, and from 5 to 7 feet deep. It is a double machine, that is, two boats fastened together side by side, each having a rake and appendages, and one wing on the outside of each boat. This river is scoured by it for a length of 12 miles into the sea at Sandwich.

Perhaps in this manner the principle of this machine might be applied to a river of considerable size by increasing the number of boats. But whether it be a single or a double machine, it is evidently only applicable where there is a running stream of water, and free egress at the mouth of the river.

Mill Street, Bermondsey,
March 7th, 1837.

W. B. HAYS.

XVI.—*Description of the Perpendicular Lifts for passing Boats from one Level of Canal to another, as erected on the Grand Western Canal. By* James Green, *M.Inst.C.E.*

It may be right, in the first instance, to observe, that these lifts have not been designed to supersede the use of locks on canals in all cases, but for a peculiar situation, in which a very considerable ascent was to be overcome within a short distance, where the supply of water was inadequate to the consumption of common locks, and the funds were insufficient for the execution of the work on a scale adapted to such locks.

The trade expected on the canal was chiefly the carriage of coal, culm for burning lime, and lime-stone, all oı which might be conveyed in a train of small boats linked together and drawn by one horse, to the number of four, six, or eight, as the occasion might require, the chief object being economy in cost, and therefore to move slowly and convey a large quantity; and under such circumstances, it must be obviously desirable that the ponds of canal between the lifts should be as long, and the lifts as few in number as possible, to prevent hindrance by too frequently detaching the boats in order to pass them singly over the lifts.

In this instance, the boats are built to carry 8 tons each, being 26 feet in length and 6½ feet in width, drawing when laden 2 feet 3 inches of water, so that a canal 3 feet in depth is sufficient for their use.

General description. Plates XVI., XVII., XVIII.

The lift consists of two chambers, similar to the chambers of a common lock, with a pier of masonry built between them; the chambers being of sufficient length and width to admit of a wooden cradle or cistern being placed in each of such chambers, and which cradles are of sufficient length and width freely to admit one of the boats to float within them. (Plate XVI.)

The cradles are furnished with water-tight lifting doors or gates at each end, so as to contain the boats afloat within them when the cradles are put in motion. (Plate XVII.)

The side walls of the chambers and the pier between them, are carried up

from foundations sufficiently below the bottom level of the lower canal, to the top bank level of the higher pond of canal. The perpendicular height of the lift here described is 46 feet, i. e. the difference in the levels of the two ponds of canal.

In the centre pier, arches are constructed longitudinally of sufficient width for a person to pass; these are connected with arches built transversely in the pier, and with platforms at the higher ends of the chambers, by which means access is had to all parts of the cradle when it is stationary at the lower level, for the purpose of any adjustment of the several parts. (Plate XVII.) The transverse arches in the pier have the effect of lessening the mass of masonry, and diffusing light within the chambers, the arches introduced in the front or retaining walls of the building are for the same purpose, as will appear by the drawings. (Plate XVIII.)

The water in the lower pond of canal is prevented from flowing into the chambers of the lift, by lift up gates or doors, and in the same way the water is cut off from the lift at the higher level. (Plate XVII.)

The floors of the chambers are sufficiently below the bottom of the lower canal to allow of the coil or gathering of the balance chains underneath the cradles, and to leave the cross beams of timber on which the cradles rest when at the lower level uninterrupted by water, and a drain is laid from each chamber to prevent the accumulation of water therein beyond the height of the bottom of the cradle.

The sides of the cradles are well secured by wrought iron knees on the inside, which are riveted to wrought iron straps on the outside. (Plate XVII.) The ends of the cradles have cast iron frames corresponding with their cross section, properly bolted and riveted to the timbers, which preserve the uniformity of figure, and render them perfectly stiff and firm. All the joints are caulked and made water-tight.

On the top of the walls of the lift a framing of cast iron is erected, consisting of 12 upright hollow columns, 9 feet high and 12 inches in diameter, which are secured to the masonry by strong wrought iron holding down bolts. The columns are braced together by the lateral and transverse beams described in the drawings, and this framing supports a longitudinal cast iron shaft, 22 feet in length and 10 inches' diameter, with couplings, as shewn in the drawings; the bearings properly turned and seated on brasses, in plummer blocks, carriages, &c. (Plates XVI. and XVII.)

On this shaft are fixed, in the manner shewn in the drawings, three cast iron wheels or pulleys, 16 feet in diameter, for the purpose of carrying the wrought iron chains which support the cradles. The opposite points in the diameter of these wheels being directly over the centre of each chamber of the lift. (Plates XVI., XVII. and XVIII.)

The two outer pulleys simply carry the chains, but the centre one besides this has a spur gear in segments fixed on one side, which working into the pinions shewn in the drawings, (Plates XVI. and XVIII.,) gives motion to the bevel gear wheels attached thereto, and which by means of a wrought iron diagonal shaft communicates with a hand gear or winch power fixed on the side of each chamber wall; this is worked by hand, for giving motion to the machinery, when necessary, without any preponderating weight of water in either of the cradles.

To this hand gear is attached a cast iron brake wheel and brake lever, for the purpose of regulating the speed of the ascent and descent of the cradles when (as generally is the case) a preponderating weight of water in the cradles is used to give them an alternate motion. (Plate XVII.)

The chains used to support the cradles are of the best wrought iron, and what is called bar chain, (Plate XVIII.,) with coupling or connecting joints and steel pins, and the wheels or pulleys are so cast as to leave proper seats for these joints, which prevent the slipping of the chains.

The cradles, as shewn in the transverse sectional view of the lift, (Plate XVIII.,) are attached to the chains by means of strong wrought iron suspension bars fixed to each side in the direction of the three pulleys. These suspension bars are connected in pairs by a cast iron beam across the cradles, at a sufficient height above the sides to allow the boat to pass under them. A round wrought iron bolt, 3 inches in diameter, is attached to the end of each chain, and passed through an aperture fitted thereto in the centre of the suspending cross beam. On these bolts is a strong square threaded screw worm, and underneath the beams a strong brass nut, and by means of these screws the cradles are adjusted to their proper horizontal position. There are also wrought iron bridle bars with nuts and screws placed diagonally from the ends of the cross beams to a link in the suspending chains, by which the transverse level or position of the cradle is adjusted.

The length of the suspending chains is so arranged, that when one cradle is at its proper level at the bottom of the lift, the other is at its proper level at

the top, and each cradle containing an equal quantity of water, the weights would be in equilibrio but for the difference in the length of chain between the cradle at the bottom and the one at top; to remove this disparity, chains of an equal weight per foot to that of the suspending chains are attached to the bottom of each cradle, with one end resting on the floor of the chambers, on which they gather under a descending cradle, and elongate with the one ascending, and thus an equilibrium is preserved. Nothing more is wanted to put the machinery in motion than a power equal to its vis inertia and friction, together with the required velocity. This power is acquired by so adjusting the chains that when one cradle is at the bottom of the lift on the proper level to receive a boat, the cradle in the opposite chamber is not quite up to the level necessary to receive a boat from the upper pond of canal, the difference found necessary in using the lifts is not quite 2 inches, producing in the cradle a preponderating weight of only one ton, but this is regulated at pleasure.

The cradles are so suspended that the facings at their higher end, when raised to the proper height, come within half an inch of the facings of the higher stop gate to the canal. The cradle is then forced forward (Plate XVII.) close to the last-mentioned facings by means of the forcing up bar of cast iron at the rear of the cradle, as shewn in the bird's eye view of the machinery. (Plate XVI.)

This bar rests by a groove in its ends on the longitudinal wrought iron tie bars, which pass in a groove in the masonry from one end of the lift to the other, and by means of strong screws and nuts bind the several parts of the work firmly together. This forcing up bar is moved by a strong square threaded horizontal screw, working in a fixed brass or bush, and moved by a hand multiplied gear, (Plate XVII.,) so that a turn or two of the winch is sufficient so to force the cradle against the framing of the stop gate at the higher end, that no water can escape between them.

The stop gate to the canal and the upper door to the cradle are so framed and furred out, that there is scarcely any space between them that will occasion a loss of water.

The stop gate of the higher level is lifted by a winch gear on the sides of the chamber, putting in motion chains attached thereto, which pass over pulleys fixed in a transverse framing of timber; the operation is easily and speedily performed, and by a strong iron bolt fixed on the higher side of the stop gate being moved, by a man's foot, into a corresponding square staple in the door of

the cradle, both doors are raised at the same time. The lifting of these doors at once occasions a flow of water from the canal into the cradle sufficient to allow the boat to pass into the canal on its proper level, and the doors being let down, the necessary preponderance of water is retained in the cradle to produce its descent, which commences on the winding back of the forcing up bar at its rear. (Plate XVII.)

The descending cradle, when arrived at the level of the surface of the water in the lower pond, comes in contact with two inverted wedges of wrought iron, fixed at the back or higher end of the lower chamber, and by sliding against them in its further descent it is forced tightly against the inner side of the framing to the lower stop gate, and the meetings become water-tight. The door of the cradle and of the stop gate of this lower level are furred out to meet in the same manner as those on the higher level. The door at the lower end of the cradle has two inverted half staples of iron fixed on the top thereof, which fit into mortices of iron in the stop gate when the cradle has arrived at its proper level, and thus by raising the stop gate in a similar way to that on the higher level, the door of the cradle is also raised, and the boats pass freely from and into the cradles. The lowering of the gates so as to inclose the boat in the cradle is, of course, done in the same way.

It will be apparent from this description of the machinery that the great desideratum in its construction is strength of material, and a common degree of attention to the arrangement of the several parts, as the principle is simply that of equally poised weights suspended by simple sheaves, so that it matters little to what height (within reasonable limits) the lift extends, provided the parts be proportionately strong. In higher lifts than those which have been already constructed, the great difference will be in the length and weight of chain, and the power to regulate the velocity of descent. The brakes to the extent used have been found sufficient to govern the motion, but other means may be resorted to for this purpose, such for instance as attaching to the centre pulley a pinion on a shaft, working by means of a crank an hydraulic plunging piston in a cylinder fixed in a cistern of water in the centre pier of the building, the motion of which might be regulated at pleasure, and by various other means which are now well understood.

With due precautions against inattention on the part of the man having the care of and working the machinery, and a proper adaptation of its parts, the system might be safely applied to passing boats of much larger tonnage than those now used in this way. The advantages of the system are,

First, economy in the expense of construction as compared with common locks.

Secondly, the saving of time in passing boats from one level to another; and thirdly, the small consumption of water as compared with common locks.

In these times, when the value of water power is so much better understood than formerly, the difficulty of obtaining a sufficient supply of water for locks is one of the greatest impediments to the formation of canals. Various contrivances have been resorted to for lessening the quantity of water required, and the development of any practical mode by which they can be accomplished to a considerable extent, must be important.

In the lifts here described, the consumption of water is about one ton to 8 tons of cargo raised from one level to the other, whilst the same weight is at the same time lowered from one level to the other; add to this the water lost to the canal by leakage of the gates, (which is in practice very small,) allowing it to be equal to that which is used in giving motion to the machine, the whole consumption is only 2 tons of water to 8 tons of cargo, whereas the consumption of water by common locks may be taken generally at 3 tons, to 1 ton of cargo; the saving in this respect is, therefore, 22 parts out of 24, or 92 per cent., very nearly. It may also be observed, that a quantity of water exactly equal in weight to the amount of the gross tonnage of boats and cargo will pass either up or down the canal in a direction contrary to that of the load,—i. e. if the trade were all downward, and the boats returned empty, a quantity of water equal to the whole weight of the loading passed down, will have been passed up from the lowest level of the canal to the highest; and vice versâ, if the trade were all upward, the same quantity of water would have passed down the canal from the top level to the bottom one, independently of the use or waste in working the lift; and this observation applies equally to the difference or balance of tonnage between the up and down trade, either way, as a quantity of water equal in weight to such difference will pass in a contrary direction; and hence arises a somewhat curious proposition,—that with these lifts and a *downward trade*, water equal in weight to the loads passed down would be absolutely carried up from the lowest to the highest level of the canal.

The time occupied in passing one boat up and another down this lift of 46 feet high, is found to be three minutes. The time occupied in passing a common lock of 8 feet rise is on an average 5 minutes, and thus nearly 30 minutes would be required to attain the rise of 46 feet by locks. Here then is a

saving in time of $\frac{9}{10}$ths, supposing the boats in each case equal in size, but as locks are seldom built for boats of less than 25 tons burden, the saving in time by passing weights in these small boats, as compared with common canal boats of 25 tons, is full $\frac{2}{3}$rds.

The merit of the first idea of passing boats from one pond of canal to another on this principle, is justly due to the late Dr. James Anderson, of Edinburgh, who published a paper on the subject in his Agricultural Survey of the County of Aberdeen, about the year 1796; but it will be seen on a perusal of that able paper, that the details by which the principle was to be carried out, were left much to the practical man.

The way in which the principle has been put in practice differs, in one essential point, very materially from that suggested by Dr. Anderson, inasmuch as he proposed, "that in order to give the upper cradle power to descend, a sufficient quantity of water should be drawn out of the lower cradle to give the required preponderance in the descending one, which quantity of water would pass by the drain from, and be entirely lost to the canal, in addition to the leakage."

By the mode in which the work has been carried into execution, the cradle which has to descend is charged, in the first instance, with so much more water than is contained in the ascending cradle, as will give the required preponderance; and this water, on the passage of the boat from the cradle into the lower pond of canal, is delivered into such lower pond, and is, therefore, available in the use of the several lifts below.

JAMES GREEN.

London, March 17, 1838.

XVII.—*On the methods of Illuminating Lighthouses, with a description of a Reciprocating Light.* *By J. T. Smith, Capt. Madras Engineers, F.R.S., A.Inst.C.E.*

The subject of improvements in the construction of lighthouses, having recently occupied a considerable share of the public attention, and its close connection with the maritime welfare of this commercial nation, rendering every step towards its accomplishment a work of utility, even should it fail to deserve notice for its scientific interest, I am induced to lay before the Institution the following brief description of an apparatus of my invention of a novel kind, which has recently been constructed under my superintendence for the Madras Government, with a view to its being sent out to that Presidency, and erected in Fort St. George.

The advantages which were contemplated by the alterations which I have succeeded in bringing to perfection in the apparatus above alluded to, have no reference to any modification of the means employed for the original production of the light, but apply more particularly to an economy introduced by a more effectual distribution of it, by whatever means it may have been generated. This saving is effected by a contrivance so simple in its operation, and at the same time so obvious when explained, that I should not have thought any description of it worthy the attention of the Institution, were I not in hopes that it might be beneficial to others that the practical success of the experiment should be made known, and desirous also to introduce it as a new principle of illumination to a place beside the two established systems, from both of which it differs, and which are now so well known as the *fixed* and *revolving* lights.

The new apparatus to which I allude, and which it is the object of this paper to describe, I have named a *Reciprocating* light, the motion which is impressed upon it being of that description; but I shall, before entering upon a more detailed explanation of it, and of the advantages which it may in some cases possess over the existing system, premise a few remarks as to the general principles of illumination.

Fixed lights. In fixed lights, as is already well known, the distribution of light is effected, according to the system hitherto adopted in England, by means of

Argand lamps and a number of parabolic reflectors placed circularly, facing outwards, and so disposed with respect to each other that each reflector is pointed towards a different part of the horizon, a very small portion of which is illuminated by it, the tendency of the reflector from its peculiar shape and catoptric properties being to collect the light of the lamp placed in its focus, and propel it in a dense beam along its axis or in the direction of the point immediately in front of it, to a very small space on each side of which its effects are confined. This space, or breadth of the luminous beam, is usually calculated at $7\frac{1}{2}$ degrees on each side of the axis; or 15° in all, consequently the number of reflectors which would be requisite to fill the whole circumference of the horizon with light, ought not to be less than the quotient of 360° by 15° or 24. If a *part* of the horizon only require illumination, a smaller number in proportion are sufficient.

Revolving lights. A revolving light may be explained by first supposing the above system of reflectors to be mounted on a frame, which is connected with machinery suited to give it a revolving motion. It is plain that if the entire system proper for a fixed light were thus made to rotate, a spectator would still see an uninterrupted beam of light *, since the diverging rays from the 24 reflectors filling up the entire circumference of the horizon, as before explained, the effect of each as seen by a spectator from a distance during the revolution would not cease till that of the succeeding one had commenced.

If we now suppose, that instead of the complete system above referred to, every alternate reflector be removed, the disposition of the remaining ones being unaltered, it will be obvious that the appearance produced would undergo a very marked change, for now on the light of any one reflector ceasing to be visible, the illumination would not be kept up as before by the action of a succeeding one, but an interval of darkness would ensue corresponding to the blank left by the removal of its adjoining reflector, and the effect of the system

* In the case here referred to the beam would be uninterrupted, for the reasons afterwards given, but it would not be *uniform* in intensity. For the tendency of each reflector being to collect the greatest quantity of light close to its axis, and proportionably less and less as we recede from it, its effects become weaker towards the edges of the space filled by its beam, so that the light is much more feebly seen by a spectator situated in the line opposite the junction of two reflectors, than when immediately in front of either of the mirrors themselves, and hence the effect of the revolution of such a system, is that of an undulating or flashing light, according to the rapidity of the motion imparted to it.

after this alteration, as viewed during rotation, would be that of a series of bright and dark periods which constitute the " flashes" and " eclipses" peculiar to the revolving lights.

This principle is both striking in its effects, and also economical as compared with the fixed lights; for it will be readily understood from what has been above explained, that if the eclipses and flashes be of equal duration, only half the number of reflectors and lamps required by a fixed light become necessary for the illumination of a complete circumference of the horizon; and it will be further obvious, that if, as is usually the case, the dark periods or eclipses be made of a *longer* comparative duration, the number requisite would be still further diminished; for instance, if the eclipses were proposed to be of double the duration of the flashes, then instead of removing every alternate reflector, as in the case above alluded to, the plan adopted would be to remove two and leave the third, thus reducing the number from the twenty-four lamps indispensable to the fixed principle, to eight only.

There is however one circumstance attendant upon this contrivance which in many situations detracts greatly from the superiority it would otherwise possess over the fixed lights, and which it is the object of the improvement which I have introduced to obviate. This defect consists in the useless expenditure of light, which is occasioned by a revolving light sweeping the *entire* circumference of the horizon, when placed in a situation where only *half* of it requires illumination. When a lighthouse is situated upon a line of coast, as most are, it is plain that no real benefit can result from illuminating the land side, and consequently in such a situation, that portion of the lantern which looks inland in lieu of being cased with glass, is always " blanked" by inserting copper plates, to avoid expense, risk of breakage, &c.

Now when a light upon the fixed principle is established in such a situation, the effect produced is precisely proportioned to the means employed, and none of the light is lost*, since none of the reflectors are pointed inland; but in a revolving light, on the other hand, this adaptation of the means to the end to be gained cannot be applied, for while the revolution continues complete, the reflector which at one time points to seaward, must a few minutes afterwards be directed towards the land, or rather against the blank wall which closes

* This regards the azimuthal distribution only, as it would be tedious and out of place here to take into consideration the vertical divergence of the rays. And as this divergence is the same in both cases, the argument is in no respect affected by its operation.

the lantern on that side; so that while one half of this system is fulfilling the purpose for which it is intended, the effects of the other half are absolutely thrown away.

This is of more importance where instead of each flash being produced by a single reflector, as in the above supposition, a number are combined (pointing in the same direction) to augment the vividness of the beam. In this case, the total number employed being greater, the absolute loss is also enhanced. In the new apparatus recently constructed for Madras, it was determined to group three reflectors together to produce each flash, and it was also decided, that intervals of darkness of double the duration of the bright periods should be allowed to intervene, to form the eclipses. These conditions would have required by the present system of revolving lights, agreeably to the explanation above given, that 8 sets of 3 reflectors each should be used, or 24 in all; but being struck whilst preparing the design for this apparatus with the manifestly unprofitable distribution above pointed out, and being very desirous, from other attendant circumstances, to diminish the number of reflectors and lamps as far as possible, without decreasing the predetermined results, it occurred to me that this might be very easily and simply effected by merely stopping the revolution of the apparatus after it had traversed a certain portion of the circumference, and then *reversing* the motion, so as to cause it to reciprocate backwards and forwards, and thereby confining the action of the reflectors disposed towards the sea to that side only, and obviating the necessity of placing any mirrors or lamps whatever on that side facing the land. I have been enabled by this means to fulfil the conditions proposed at $\frac{5}{8}$ths of the expense which would have attended an adherence to the old principle; and the saving might have been further increased, to nearly one half, had I not been desirous to avoid the possibility of any defect in the distribution of the light near the coasts, by extending the limits of the illuminated arc to more than four points of the compass inland on each side.

Objections to reciprocating light.

This system of illumination is obviously inapplicable to situations where, from the multitude of beacons on a dangerous coast, it becomes necessary to have recourse to observations on the length of the eclipses, or to the time elapsing between the periodic recurrence of the flashes, as the means whereby the particular light is to be determined. But it has hitherto, I believe, been found unnecessary in British lighthouses to rest entire dependence on the differences in the periods of revolution, and it appears

prudent to avoid having recourse to this means of discrimination, since it is the least secure, and open to various objections. Where, however, this system is indispensable, the reciprocating light cannot be used; for, although the total quantities of light and darkness seen by a spectator in every position are constant, yet from the peculiar nature of the motion, the durations of the flashes and eclipses vary with every new position of the observer, a circumstance which, if not understood, might lead to mistake and fatal consequences.

These remarks, however, apply only to those cases where, from the existing number of similar works, it becomes important to avoid the danger of confusion, and are inapplicable when it is proposed to adopt it in situations sufficiently remote to be secure from the liability of incurring that evil. In the present case, for instance, the reciprocating light to be erected at Madras will be the only moving light on the whole coast of India, and hence cannot possibly be mistaken for any other at present in existence; but I consider it would be equally safe to introduce the system wherever the determination of the precise periods does not enter as an indispensable condition, and in such situations it will be strongly recommended by its economy, as the annual saving effected by it will be found to be well worthy of consideration, in addition to its being attended by other advantages, such as the reduction of weight and bulk, superior cheapness in *first* cost, and diminution of the labour requisite to keep the apparatus in order, &c.

Mechanical arrangements.

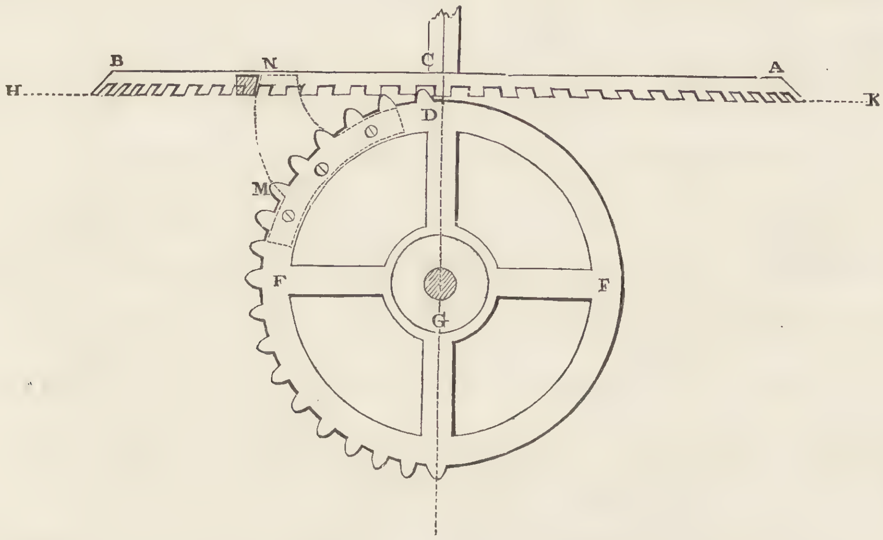
Having thus given an outline of the nature and peculiarities of the system above described, it only remains for me to add a few remarks regarding the nature of the machinery by which the movement is effected.

The whole of the reflectors are fixed in their proper positions to a reflector frame, attached to a central spindle placed vertically, and to which motion is communicated from a machine of common construction (moved by a weight and regulated by fans) by means of a couple of bevelled wheels, one of which is fixed on the vertical spindle just mentioned, and hence revolves in a horizontal plane; the other turns in a plane at right angles to the above on a vertical plane, its arbor or axis being at right angles to the spindle. Now, if instead of this single vertical wheel, acting continually on one side of the horizontal one above mentioned, another one be similarly situated on its *opposite* side, and engaged in the teeth on its margin, these two wheels are mounted on the same arbor and consequently turn in the same direction, it will be evident that they would,

if successively engaged, produce *opposite* motions in the spindle and the apparatus, but that if both were engaged at the same time no motion at all could be effected, since by their opposite tendencies they would act against each other.

This successive action, therefore, is effected by fixing both of the wheels upon the arbor in the same manner as if they were singly employed, that is, with their teeth engaged at the proper pitch in the horizontal wheel above them, and then by cutting away those of the alternate semi-circumferences of either, so that while those are engaged and produce motion in one direction, the blank circumference of the other is presented, and the moment the former ceases to act, the teeth of the latter come into play, producing an opposite movement.

This apparatus, upon execution and trial, was found to produce the intended effect very steadily, but I soon observed, that however satisfactorily it might act when well set up, it was incapable of withstanding the effect of those disturbances which long friction and wear of the parts, or accidents and ill treatment might subject it to, and without a perfect security against which I should have felt it unsafe to despatch it to so distant a settlement. The reason of this will be seen by reference to the figure, in which ACB represents the horizontal bevelled wheel, and EDF represents one of the vertical wheels above alluded to, at the very moment when the last tooth is escaping from its engagement with the horizontal wheel, and when the change in the movement is about to take place. Now the conditions of the light demand that there should be no material loss of time in reversing the motion, that is, that the movement from C to A in the upper wheel should commence in not more than a second or two after that in the direction of C to B caused by the action of the wheel EDB has ceased. Moreover, it will be plainly seen that as the change of motion which ensues after the tooth D has quitted its hold, causes the whole range of teeth from C to B immediately to return in the direction of K, passing over the head of D, there would be some risk, (more particularly if by any derangement the wheel BCA should have become swayed out of its proper position, and its edge fall below the line HK,) of these teeth striking the top of D on their return; or what would be as bad, of their failing to disengage it at the proper time, unless before this return movement commenced the top of D had dipped sufficiently below the line of their path HK, to be out of the reach of any such accident.



But it unfortunately happens that at the very point only, where the tooth D is situated, the dip below the horizontal line, occasioned by the curvature of its path, amounts to nothing, (being represented by the versed sine of the angle formed by the radius drawn to it, with the vertical CG,) and is hardly perceptible until it has reached a considerable distance from the verticle position, so that before it would have amounted to $\frac{1}{8}$th of an inch, which I satisfied myself would be sufficient to place the security of the movement beyond the reach of probable accident, the delay or loss of time would have amounted to not less than 7 or 8 seconds. It occurred to me, however, that if I could make the final connection between the wheels by means of a tooth situated on a part of the wheel EDF endowed with a more oblique motion, that it would then be in my power even to increase the clearing space above mentioned if necessary, without the sacrifice of any material delay. With this view I designed the tooth represented in the figure by dotted lines; and it ought more properly to be termed a cam or snail, as it acts upon a short straight pin projecting from the side of the horizontal wheel, and communicates to it precisely the same motion as it would receive from the teeth, which now become unnecessary and might be entirely removed. In order to ensure the exact equivalence of the motion to that for which it is substituted, and to cause the cam to follow close to the circumference of the upper wheel, its edge has a double

curvature, that of MN, which is seen in the figure, being a cycloid formed by the circle DEF, and its face is also twisted in a spiral direction in order to accommodate it to the varying inclination of the spiral pin it acts on. The adoption of this simple contrivance has completely obviated the difficulty which seemed to stand in the way of perfect success, and since it has been applied, although the interval elapsing between the motions is only 2 seconds, I have found the apparatus to work so completely free from the risk I was apprehensive of, that I have as yet found it quite unnecessary to do more than merely file the tops of the last two teeth, amply sufficient space having been gained by that means; but it may perhaps be advisable to remove a little more previous to transferring the machine to the management of the rude hands to whose care it will in future be entrusted.

J. T. SMITH,
Captain Madras Engineers.

London, June, 1837.

XVIII.—*Experiments on the Flow of Water through small Pipes.* *By W. A. Provis, M.Inst.C.E.*

Having had occasion to make some experiments on the flow of water through pipes of different lengths, it has occurred to me that a copy of them may not be unacceptable to the Members of the Institution of Civil Engineers.

The experiments were made with lead pipes of $1\frac{1}{2}$ inch diameter, drawn at the manufactory of Mr. James Easton, in Guildford Street, Southwark, and to that gentleman I am indebted for the use of a very commodious building, and such workmen as I required.

The pipes were drawn in 15 feet lengths, soldered together with care, so as to avoid as far as practicable any irregularity of aperture at the joinings. The united pipe was stretched on a wooden beam resting on upright posts in such manner that the pipe could be kept horizontal or depressed through its whole length towards the discharging end.

Into the upper end of the pipe was inserted a stop cock of similar bore, and from this cock the lengths of the pipe were measured. The opposite end of the cock was inserted into a cistern 2 feet square on the plan and 3 feet in height, graduated upwards from the centre of the bore of the cock. A second cistern was placed above that just described with a short connecting pipe and cock, by which the lower cistern could be supplied with water.

To the lower end of the pipe was attached by an universal joint an open trunk or spout, by means of which the water from the pipe could be turned at pleasure into or outside of a receiver, the capacity of which was 4 cubical feet. The receiver had a valve at the bottom by which the water it contained could be discharged.

When an experiment was to be made, the highest cistern at the upper end of the pipe was filled with water, and that below it (the one graduated) was also filled to the height required for the individual experiment. An assistant was stationed to keep the water in the lower cistern constantly at the required height by a continued supply from the upper one. A second assistant was placed at the cock which discharged into the pipe, to turn on the water when the signal should be given that all was ready.

At the lower end of the pipe the moveable spout was held by a third

assistant ready to turn its stream into the receiver when so directed. To mark the time on a stop watch, and register the result, was my own duty.

When all was thus prepared, and the seconds hand of the watch indicated a complete minute, I gave the first signal "now." The cock was instantly turned and the water flowed into the upper end of the pipe. My assistant at the lower end watched and gave the word "here" when the water had arrived. I then again noted the time. The water was allowed to run to waste till the stream through the pipe appeared regular and steady, after which I waited till the watch indicated another complete minute, when at the word "now" the water was turned by means of the moveable spout into the receiver. When the word "full" was cried out by my assistant I noted the time, and so finished the experiment.

Considerable difference was observed in the time required for the run of the water through the pipe, it being influenced by the dryness or moisture of the inside, as well as by the accumulation of air within it, when the pipe was level or only slightly inclined. With a level pipe and its inside nearly dry (as was the case sometimes when we commenced the day's experiments) the time required for passing the water through the pipe was nearly 50 per cent. more than after the inside of the pipe had been thoroughly wetted.

In all cases where the pipe was level or nearly so, and more especially in the longer lengths, there were frequent regurgitations of the water owing to accumulated air within the pipe. The experiments, however, on the time in filling the receiver were not commenced till the stream through the pipe had become to all appearance perfectly equable.

The experiments were generally made in duplicate to guard against any great error, and when any considerable discrepancy appeared in the first two, a third experiment was added. The results are stated in the following Tables.

Length of Pipe of $1\frac{1}{2}$ inches inside diameter.	Inclination of pipe.	Head of water at upper end of pipe.	Time from turning the water into the upper end of the pipe to its reaching the lower end.	Time in filling the receiver.	Discharge in cubical feet per minute.	Mean discharge per minute.	Observations.
Experiments Nos. 1 to 12.							
Feet.		Inches.	Seconds.	Seconds.	Cubical feet.	Cubical feet.	
100	Level	35	16	106	2·264	......	Pipe dry.
...	......	...	11	105	2·285	2·275	In these trials the discharging end of the pipe appeared filled.
...	......	30	10	121	1·983	1·991	
...	......	...	14	120	2		
...	......	24	12	137	1·752	1·745	
...	......	...	15	138	1·739		
...	......	18	14	163	1·472	1·476	Discharging end of pipe nearly full.
...	......	...	16	162	1·481		
...	......	12	10	209	1·148	1·151	Discharging end of pipe about $\frac{3}{4}$ths full.
...	......	...	13	208	1·154		
...	......	6	27	319	·752	·753	Discharging end of pipe not half filled.
...	......	...	32	318	·754		
Experiments Nos. 13 to 25.							
80	Level	35	13	...	......	......	Rejected, as the valve of the receiver was not closed.
...	......	...	not observed	96	2·5	2·5	Bore of the pipe at lower end nearly filled with water.
...	......	...	11	96	2·5		
...	......	30	10	106	2·261	2·264	
...	......	...	11	106	2·264		
...	......	24	not observed	120	2	2·008	
...	......	...	20	119	2·017		
...	......	18	14	143	1·678	1·684	
...	......	...	16	142	1·69		
...	......	12	17	177	1·356	1·352	Lower end of pipe not quite filled.
...	......	...	16	178	1·348		
...	......	6	19	267	·898	·901	Lower end of pipe about half filled.
...	......	...	24	265	·905		
Experiments Nos. 26 to 38.							
80	1 in 112	35	14	86	2·79	2·774	The discharging pipe appeared filled at the lower end.
...	......	...	14	87	2·758		
...	......	30	15	92	2·608	2·594	
...	......	...	15	93	2·58		
...	......	24	17	102	2·353	2·353	
...	......	...	17	102	2·353		
...	......	18	19	116	2·069	2·106	
...	......	...	19	112	2·143		
...	......	...	18	114	2·105		
...	......	12	23	132	1·818	1·811	
...	......	...	23	133	1·804		
...	......	6	28	163	1·472	1·476	Lower end of discharging pipe not quite filled.
...	......	...	27	162	1·481		

Length of Pipe of $1\frac{1}{2}$ inches inside diameter.	Inclination of pipe.	Head of water at upper end of pipe.	Time from turning the water into the upper end of the pipe to its reaching the lower end.	Time in filling the receiver.	Discharge in cubical feet per minute.	Mean discharge per minute.	Observations.
			Experiments Nos. 39 to 50.				
Feet.		Inches.	Seconds.	Seconds.	Cubical feet.	Cubical feet.	
80	1 in 56	35	13·5	79	3·038	3·077	Discharging pipe appeared filled at the lower end.
...	......	...	13	77	3·116		
...	......	30	14	82	2·927	2·909	
...	......	...	14·5	83	2·891		
...	......	24	15	89·5	2·681	2·673	
...	......	...	15	90	2·666		
...	......	18	18	98	2·449	2·461	
...	......	...	18	97	2·474		
...	......	12	19	109	2·202	2·212	
...	......	...	20	108	2·222		
...	......	6	24	123	1·951	1·951	Lower end of discharging pipe very nearly filled.
...	......	...	23	123	1·951		
			Experiments Nos. 51 to 63.				
80	1 in 37·33	35	13	71	3·38	3·356	Discharging pipe appeared full.
...	......	...	13	72	3·333		
...	......	30	13	75	3·2	3·179	
...	......	...	13·5	76	3·158		
...	......	24	14·5	82	2·926	2·926	
...	......	...	15·5	82	2·926		
...	......	18	16	86	2·79	2·774	
...	......	...	17	87	2·758		
...	......	12	17·5	94·5	2·539	2·513	
...	......	...	18	97	2·474		
...	......	...	17	95	2·526		
...	......	6	20	104	2·308	2·308	Lower end of discharging pipe not quite filled.
...	......	...	21	104	2·308		
			Experiments Nos. 64 to 75.				
60	Level	35	10	83	2·891	......	Dry pipe.
...	......	...	7·5	84	2·857	2·874	Discharging pipe appeared filled.
...	......	30	9	92	2·608	2·594	
...	......	...	10	93	2·58		
...	......	24	9	104	2·308	2·302	
...	......	...	9	104·5	2·296		
...	......	18	10	123	1·951	1·959	
...	......	...	11	122	1·967		
...	......	12	12·5	155	1·548	1·558	
...	......	...	13	153	1·568		
...	......	6	18	229	1·048	1·052	Discharging pipe nearly filled at lower end.
...	......	...	19	227	1·057		

Length of Pipe of $1\frac{1}{2}$ inches inside diameter.	Inclination of pipe.	Head of water at upper end of pipe.	Time from turning the water into the upper end of the pipe to its reaching the lower end.	Time in filling the receiver.	Discharge in cubical feet per minute.	Mean discharge per minute.	OBSERVATIONS.
			EXPERIMENTS Nos. 76 to 87.				
Feet.		Inches.	Seconds.	Seconds.	Cubical feet.	Cubical feet.	
60	1 in 112	35	10	77	3·117	3·127	Discharging pipe appeared filled.
...	......	...	9	76·5	3·137		
...	......	30	10·5	83	2·891	2·891	
...	......	...	10	83	2·891		
...	......	24	12	91	2·637	2·637	
...	......	...	11·5	91	2·637		
...	......	18	13	103	2·33	2·324	
...	......	...	14	103·5	2·318		
...	......	12	15	122	1·967	1·975	
...	......	...	16	121	1·983		
...	......	6	19	150	1·6	1·6	Discharging pipe not quite full at lower end.
...	......	...	19	150	1·6		
			EXPERIMENTS Nos. 88 to 99.				
60	1 in 56	35	9	71	3·38	3·38	Discharging pipe appeared full.
...	......	...	9	71	3·38		
...	......	30	10	75	3·2	3·221	
...	......	...	9	74	3·243		
...	......	24	11	82	2·927	2·927	
...	......	...	11	82	2·927		
...	......	18	11	91	2·637	2·637	
...	......	...	12	91	2·637		
...	......	12	13·5	103	2·33	2·341	
...	......	...	14	102	2·353		
...	......	6	16·5	119	2·017	2·008	Discharging pipe not quite full at lower end.
...	......	...	17	120	2		
			EXPERIMENTS Nos. 100 to 111.				
60	1 in 37·33	35	9	66	3·636	......	Pipe dry.
...	......	...	8	66	3·636	3·636	Discharging pipe appeared full.
...	......	30	9	70	3·428	3·428	
...	......	...	9	70	3·428		
...	......	24	10	75	3·2	3·2	
...	......	...	10	75	3·2		
...	......	18	11	81·5	2·944	2·944	
...	......	...	11·5	81·5	2·944		
...	......	12	13	89	2·696	2·681	
...	......	...	13	90	2·666		
...	......	6	15	101	2·376	2·382	Discharging pipe not quite full at lower end.
...	......	...	15·5	100·5	2·388		

Length of pipe of $1\frac{1}{2}$ inch inside diameter.	Inclination of pipe.	Head of water at upper end of pipe.	Time from turning the water into the upper end of the pipe to its reaching the lower end.	Time in filling the receiver.	Discharge in cubical feet per minute.	Mean discharge per minute.	OBSERVATIONS.
			EXPERIMENTS Nos. 112 to 123.				
Feet.		Inches.	Seconds.	Seconds.	Cubical feet.	Cubical feet.	
40	Level	35	6	68	3·53	....	Pipe dry.
...	......	...	4	69	3·478	3·504	Discharging pipe appeared full.
...	......	30	6	75·5	3·178	3·178	
...	......	...	6	75·5	3·178		
...	......	24	6	86	2·79	2·823	
...	......	...	6·5	84	2·857		
...	......	18	6	100·5	2·388	2·394	
...	......	...	7	100	2·4		
...	......	12	9	128	1·875	1·882	
...	......	...	9	127	1·889		
...	......	6	12	190	1·263	1·26	
...	......	...	12	191	1·256		
			EXPERIMENTS Nos. 124 to 135.				
40	1 in 112	35	5	64	3·75	3·721	Discharging pipe full at the lower end.
...	......	...	5·5	65	3·692		
...	......	30	6	71	3·38	3·404	
...	......	...	6	70	3·428		
...	......	24	6	77	3·116	3·096	
...	......	...	6·5	78	3·077		
...	......	18	7·5	88	2·727	2·711	
...	......	...	7	89	2·696		
...	......	12	9	105	2·285	2·296	
...	......	...	9	104	2·308		
...	......	6	12	137	1·752	1·752	
...	......	...	12	137	1·752		
			EXPERIMENTS Nos. 136 to 147.				
40	1 in 56	35	4·5	60·5	3·967	3·967	Discharging pipe appeared quite full.
...	......	...	4·5	60·5	3·967		
...	......	30	6	64·5	3·721	3·735	
...	......	...	5·5	64	3·75		
...	......	24	6	69·5	3·453	3·428	
...	......	...	6	70·5	3·404		
...	......	18	7	80	3	3·019	
...	......	...	7	79	3·038		
...	......	12	8	92·5	2·594	2·594	
...	......	...	8	92·5	2·594		
...	......	6	10·5	111	2·162	2·172	
...	......	...	9·5	110	2·182		

Length of pipe of $1\frac{1}{2}$ inch inside diameter.	Inclination of pipe.	Head of water at upper end of pipe.	Time from turning the water into the upper end of the pipe to its reaching the lower end.	Time in filling the receiver.	Discharge in cubical feet per minute.	Mean discharge per minute.	Observations.
Experiments Nos. 148 to 159.							
Feet.		Inches.	Seconds.	Seconds.	Cubical feet.	Cubical feet.	
40	1 in 37·33	35	4	57	4·21	4·286	Discharging pipe appeared quite full.
...	......	...	5	55	4·363		
...	......	30	6	60	4	3·951	
...	......	...	5·5	61·5	3·902		
...	......	24	6	66·5	3·609	3·582	
...	......	...	6	67·5	3·555		
...	......	18	6	73·5	3·265	3·276	
...	......	...	6·5	73	3·287		
...	......	12	7	81·5	2·945	2·945	
...	......	...	8	81·5	2·945		
...	......	6	10	96	2·5	2·48	
...	......	...	9·5	97·5	2·461		
Experiments Nos. 160 to 171.							
20	Level	35	2·5	53	4·528	4·528	Discharging pipe appeared full.
...	......	...	2	53	4·528		
...	......	30	2·5	58	4·138	4·138	
...	......	...	2	58	4·138		
...	......	24	3	65·5	3·664	3·664	
...	......	...	3	65·5	3·664		
...	......	18	...	77	3·116	3·116	
...	......	...	3·5	77	3·116		
...	......	12	3	96	2·5	2·487	
...	......	...	3	97	2·474		
...	......	6	4	144	1·666	1·666	
...	......	...	4·5	144	1·666		
Experiments Nos. 172 to 183.							
20	1 in 112	35	2	50·5	4·752	4·776	Discharging pipe appeared quite full.
...	......	...	2	50	4·8		
...	......	30	2	55	4·363	4·363	
...	......	...	3	55	4·363		
...	......	24	2·5	60·5	3·967	3·95	
...	......	...	2·5	61	3·934		
...	......	18	4	70	3·428	3·428	
...	......	...	3·5	70	3·428		
...	......	12	3·5	86	2·79	2·782	
...	......	...	not noted.	86·5	2·774		
...	......	6	5	117	2·051	2·06	
...	......	...	4·5	116	2·069		

Length of pipe of $1\frac{1}{2}$ inch inside diameter.	Inclination of pipe.	Head of water at upper end of pipe.	Time from turning the water into the upper end of the pipe to its reaching the lower end.	Time in filling the receiver.	Discharge in cubical feet per minute.	Mean discharge per minute.	Observations.
			Experiments Nos. 184 to 195.				
Feet.		Inches.	Seconds.	Seconds.	Cubical feet.	Cubical feet.	
20	1 in 56	35	2	48	5	4·949	Discharging pipe appeared quite full.
...	......	...	2·5	49	4·898		
...	......	30	2·5	53	4·528	4·486	
...	......	...	3	54	4·444		
...	......	24	3	58	4·138	4·138	
...	......	...	3	58	4·138		
...	......	18	3	66	3·636	3·636	
...	......	...	3	66	3·636		
...	......	12	3·5	81	2·963	2·981	
...	......	...	3·5	80	3		
...	......	6	4·5	103·5	2·318	2·313	
...	......	...	4·5	104	2·308		
			Experiments Nos. 196 to 208.				
20	1 in 37·33	35	2	46	5·217	5·217	Discharging pipe appeared quite full.
...	......	...	2·5	46	5·217		
...	......	30	2·5	51	4·706	4·802	
...	......	...	3	49	4·898		
...	... ..	24	3	55·5	4·324	4·326	
...	......	...	3	54	4·444		
...	......	...	2·5	57	4·21		
...	......	18	3	63	3·809	3·809	
...	......	...	4	63	3·809		
...	......	12	3	74	3·243	3·243	
...	......	...	3·5	74	3·243		
...	......	6	4·5	91	2·637	2·622	
...	......	...	4·5	92	2·608		

By a different arrangement of the foregoing experiments, the results shewn in the following Tables are obtained.

Fall of Pipe.	Lengths of Pipe. 100 feet.	80 feet.	60 feet.	40 feet.	20 feet.
Head of Water, 35 Inches. Discharge in cubical feet per minute.					
Level	2·275	2·5	2·874	3·504	4·528
1 in 112	......	2·774	3·127	3·721	4·776
2 in 112	......	3·077	3·38	3·967	4·949
3 in 112	......	3·356	3·636	4·286	5·217
Head of Water, 30 Inches.					
Level	1·991	2·264	2·594	3·178	4·138
1 in 112	......	2·594	2·891	3·404	4·363
2 in 112	......	2·909	3·221	3·735	4·486
3 in 112	......	3·179	3·428	3·951	4·802
Head of Water, 24 Inches.					
Level	1·745	2·008	2·302	2·823	3·664
1 in 112	......	2·353	2·637	3·096	3·95
2 in 112	......	2·673	2·927	3·428	4·138
3 in 112	......	2·926	3·2	3·582	4·326
Head of Water, 18 Inches.					
Level	1·476	1·684	1·959	2·394	3·116
1 in 112	......	2·106	2·324	2·711	3·428
2 in 112	......	2·461	2·637	3·019	3·636
3 in 112	......	2·774	2·944	3·276	3·809
Head of Water, 12 Inches.					
Level	1·151	1·352	1·558	1·882	2·487
1 in 112	......	1·811	1·975	2·296	2·782
2 in 112	......	2·212	2·341	2·594	2·981
3 in 112	......	2·513	2·681	2·945	3·243
Head of Water, 6 Inches.					
Level	·753	·901	1·052	1·26	1·666
1 in 112	......	1·476	1·6	1·752	2·06
2 in 112	......	1·951	2·008	2·172	2·313
3 in 112	......	2·308	2·382	2·48	2·622

An examination of the results shews,—

1. That when the pipes were level, the quantities of water discharged through different lengths were nearly in the inverse ratio of the square roots of those lengths.
2. That comparing the discharge with that passed through the 100 feet pipe, the departure from this rule appears greatest in the short or 20 feet lengths of pipe, when under the pressure of the greatest head of water. With a head of 6 inches of water, the rule would give about $\frac{1}{100}$th more than the observed discharge; while with a head of 35 inches of water, the rule gives about $\frac{1}{9}$th more than the actual discharge. The intermediate heads shew intermediate differences.
3. That by giving the pipes a regular and uniform descent, the discharge is increased in a greater proportion through the long pipes than through the short ones.
4. That by increasing the head of water pressing at the upper ends of the pipes, the increase of discharge is nearly in the same proportion through the long and the short lengths.

Had circumstances permitted, I should have extended the series of experiments to pipes of different bores, and endeavoured to have drawn from them some definite and useful practical rules; but the building which I had had the use of was pulled down, in order to erect cottages and workshops on its site. The subject, however, is one to which I shall probably again direct my attention, and any observations that I may make will be at the service of the Institution, if thought worthy of acceptance.

W. A. PROVIS.

24, Abingdon Street,
May 19th, 1838.

XIX.—*Experiments on the Power of Men.* *By* Joshua Field, *V.P.Inst.C.E., F.R.S.*

In this paper are recorded the results of some experiments made to ascertain the working power of men with winches, as applied to cranes. The experiments were undertaken with a view of ascertaining the effect men can produce working at machines or cranes for short periods, as compared with the effect which they produce working continuously.

The apparatus, a crane of rough construction in ordinary use, and not prepared in any manner for the experiments, consisted of two wheels of 92 and 41 cogs, and two pinions of 11 and 10 cogs; the diameter of the barrel, measuring to the centre of the chain, was $11\frac{3}{4}$ inches, and the diameter of the handle 36 inches. The ratio of the weight to the power on this combination is 105 to 1.

The weight was raised in all cases through $16\frac{1}{2}$ feet, and so proportioned in the different experiments as to give a resistance against the hands of the men of 10, 15, 20, 25, 30, and 35 lbs. *plus* the friction of the apparatus.

The resistance occasioned by the friction of the apparatus is a constant element in all machines, and of much the same amount in most cranes, and my object being to obtain some practical results on the power of men in raising weights on a system of machinery, I did not think it necessary to make any experiment for ascertaining the amount of this resistance in the present instance.

In the following table I have set down the statical resistance at the handle, the weight raised in each experiment, the time in which the weight was raised, and the remarks which were made at the time with respect to the men. A column also expressing the power or effect by the number of pounds raised one foot high in one minute is added. It will be necessary to add a few words respecting the construction of this column.

In order to compare these experiments with each other, these results must be reduced to a common standard of comparison, and it is very convenient to express the results of such experiments by the pounds raised one foot high in one minute, this being the method of estimating horses' power. The number is in

each case obtained in the following manner. I will take the first experiment.

Here 1050 lbs. was raised $16\frac{1}{2}$ feet high in 90″; this is equivalent to ($1050 \times 16{\cdot}5 =$) 17325 lbs. raised one foot high in 90″, which is equivalent to ($17325 \div 1{\cdot}5 =$) 11550 lbs. raised one foot high in one minute. In this case then

$$\text{the man's power} = 11550.$$

The same calculations being pursued in the other cases, give the numbers constituting the last column of the following table.

TABLE.

No. of Experiment.	Statical resistance at handle.	Weight raised.	Time in seconds.	Time in minutes.	Remarks.	Man's power.
I.	10	1050	90	1·5	Easily by a stout Englishman	11550
II.	15	1575	135	2·25	Tolerably easily by the same man	11505
III.	20	2100	120	2	Not easily by a sturdy Irishman	17325
IV.	25	2625	150	2·5	With difficulty by a stout Englishman	17329
V.	30	3150	150	2·5	With difficulty by a London man	20790
VI.	35	3675	132	2·2	With the utmost difficulty by a tall Irishman	27562
VII.	...	......	150	2·5	With the utmost difficulty by a London man, same as Experiment V.	24255
VIII.	...	......	170	2·83	With extreme labour by a tall Irishman	21427
IX.	...	......	180	3	With very great exertion by a sturdy Irishman, same as Experiment III.	20212
X.	...	......	243	4·05	With the utmost exertions by a Welshman	15134
XI.	...	......	35	......	Given up at this time by an Irishman	......

We may consider Experiment IV. as giving a near approximation to the maximum power of a man for two minutes and a half; for in all the succeeding experiments the man was so exhausted as to be unable to let down the weight. The greatest effect produced was that in Experiment VI. This, when the friction of the machine is taken into the account, is fully equal to a horse's power, or 33,000 lbs. raised one foot high in one minute. Thus, it appears, that a very powerful man, exerting himself to the utmost for two minutes, comes up to the constant power of a horse, that is, the power which a horse can exert for eight hours per day.

JOSHUA FIELD.

Lambeth, May, 1826.

XX.—*Particulars of the construction of the Floating Bridge lately established across the Hamoaze, between Torpoint in the County of Cornwall, and Devonport in Devonshire. By* JAMES *M.* RENDEL, *M.Inst.C.E., &c., &c.*

Introductory remarks.

BEFORE bringing under the notice of our Institution the particulars of a work, new in all the arrangement of its details, if not in principle, and professing to be a valuable addition to the existing means of promoting internal communication, I deemed it necessary to submit to the delay of a few years, that experience might decide its pretensions to the countenance of a society formed for the promotion of practical information, and enrolling amongst its members most of the eminent engineers of the day.

I have also refrained from a published description of any kind, for besides the anxiety I have always felt that the invention should stand for just what it is really worth, I have from the beginning been desirous that its first public introduction should be made to this Institution.

It is now six years since the first floating bridge upon the principle of those I am about to describe, was established by me across the estuary of the Dart at Dartmouth, and four years have elapsed since the work delineated in the accompanying drawings, and more fully described in this paper, was established across the Hamoaze, between Torpoint and Devonport. From the want of experience, which is found almost always to limit the success of first efforts involving many new arrangements and adaptations of machinery, the success of the Dartmouth floating bridge was but partial; still it was sufficient to justify my undertaking the much more difficult work now about to be described, and to give my employers encouragement to entrust me with their confidence. The result, as I shall now proceed to shew, has been such as to be highly satisfactory to them, and consequently gratifying to myself.

Establishment of the Torpoint ferry.

In the year 1790, the Right Honourable the Earl of Mount Edgecumbe, and Reginald Pole Carew, Esq., as owners of a large property in the neighbourhood of Devonport, obtained an Act of Parliament, which authorized them to establish a ferry across the Hamoaze, from Torpoint on the west or Cornwall side, to the Devonshire shore, a little to the north of

Devonport, which town, then called Plymouth Dock, had become populous, and the mart for the produce of the opposite part of the county of Cornwall. The ferry accordingly became one of considerable traffic, and the accommodation it afforded, though limited to that derivable from common ferry boats, promoted buildings on the shores on either side, till at length, in 1829, several noblemen and gentlemen of wealth and influence in the neighbourhood, associated themselves and subscribed a considerable capital for improving the accommodation of the ferry, by establishing a twin steam boat upon the model of those then in use at Dundee. With this view, they became lessees of the ferry under a lease for 21 years. In less than two years their energy and anxiety for the accommodation of the public enabled them to make trial of this vessel, which, though built upon the Dundee model, both as regarded the machinery and boat, and executed under the most able professional advice, proved a complete failure. The tides were found too strong, and the line of passage too direct across the current, to enable the vessel to make her passages when there was either tide or wind to encounter.

Company formed to establish a steam-boat similar to that at Dundee, &c.

This failure was the more discouraging from the liberality with which the work had been conducted, and the disappointment was great to the whole of the populous neighbourhood, which had expected from the establishment of this steam boat the means of easy transit for carriages, &c., as well as for foot passengers.

Proposition for the establishment of the Floating Bridge.

In the dilemma occasioned by the failure of the twin steam-boat, the practicability of establishing a floating bridge after the model of that at Dartmouth, was made a subject of enquiry, and I was applied to as the author of that work. The greater width, depth, and current of the Hamoaze than of the Dart, were matters for anxious deliberation, before I could bring myself to report in favour of a trial. Besides which, the failure of a plan that was reported to have succeeded at the wider and more important ferry of Dundee, and the but partial success of the Dartmouth bridge, were, to a certain extent, discouraging circumstances; still I felt that the failure of the one, and the limited success of the other, proceeded from very obvious though opposite causes, the one growing out of inadaptation, the other from errors which more or less attend first efforts, or in other words from a want of experience.

After a very mature consideration, therefore, of all the circumstances of the two cases, I reported my opinion in favour of the practicability of establishing

the floating bridge, which I shall proceed to describe, prefacing my narrative by some particulars of its site.

Particulars of the site of the Floating Bridge. Plate XIX.

The width of the river at the site of the bridge at high water is 2550 feet, and at low water 2110 feet. The greatest depth at high water is 96 feet, aud as spring tides rise 18 feet, the depth at low water is 78 feet. As will be seen by the section of the site in the plate, the greatest depth is at about $\frac{1}{3}$d of the width from the west shore, the bottom on each side forming a tolerably regular curve to low-water mark. The strength of the current at ordinary spring tides, is from 260 feet per minute, or nearly three knots an hour, to 330 feet per minute, or $3\frac{3}{4}$ knots an hour, varying in different parts of the line of passage, but heavy land floods, accompaned by a north-west wind, make the ebb tides run with a velocity of 430 feet per minute, or nearly 5 knots an hour; for which we had consequently to provide.

The site lies directly at right angles to the line of current, a disadvantage that could not be avoided, as the moorings of the ships of war prevented the selection of an oblique line of direction. As to the exposure of the site, I cannot better explain its degree than by stating that it is not uncommon for the ships lying in ordinary in the immediate vicinity of the bridge to drag their moorings. This has happened two or three times since the establishment of the floating bridge.

General description of the floating bridge and landing places on each side of the river.

As will be seen on reference to Plates XX., XXI., and XXII., the bridge is a large flat bottomed vessel, of a breadth or width nearly equal to its length, divided in the direction of its length into three divisions, the middle being appropriated to the machinery which impels it, and each of the side divisions to carriages and traffic of all kinds. These side divisions or decks are raised from 2 feet to 2 feet 6 inches above the line of floatation, and by means of strong and commodious drawbridges or platforms, hung at each end of each deck, carriages drive on and off the deck from the landing place, embarking and disembarking thereby, without difficulty, or occasion for the least disturbance of horses or passengers, who remain in their places during the time of crossing the river. To make the passage certain and safe in any weather, and by night as well as by day, the bridge is guided by two chains, which, passing through it over cast iron wheels, are laid across the river and fastened to the opposite shores, consequently forming as it were a road, along which the bridge is made to travel forward and back from shore to shore as required; as will be better understood by a reference to Plate XIX. It will

be seen on reference to Plate XXIII., that two small steam engines are employed as the moving power by turning a shaft, on each end of which there is a large cast iron wheel whereon the guide chains rest. The peripheries of these wheels are cast with sockets fitted to the links of the chain, so that when the wheels are stationary, the bridge is, as it were, moored by the chains, but when put in motion by the steam engines, it is moved in the reversed direction of, and the same velocity as the wheels. The landing places on each shore are simple inclined planes from low water mark to two feet above high water mark, formed to a slope or inclination of 1 in 12 or 1 in 14, and as the bridge approaches, the drawbridge is lowered on the plane; the draught of water of the bridge, and the projection of the drawbridge being such that carriages, &c., are disembarked or embarked dry, or considerably above the water mark, whilst the bridge is all afloat, and out of danger of grounding or drifting, being held fast by the chains.

To prevent the chains being so tight as to interrupt the free navigation of the estuary, or to endanger their breaking, instead of being fastened or moored to the shores, their ends have heavy weights attached to them in shafts sunk at the head of each landing place, as shewn on Plate XIX. Of course these weights rise and fall as the strain upon the chains becomes more or less, and prevents the tension ever exceeding the balance weights, which are considerably below the weight to which the chains have been proved.

Details of the wood work of the bridge. Plates XX., XXI. and XXII.

The general elevation and plan shewn on Plate XX., and the following dimensions, will sufficiently explain the capacity of the bridge. The length, *exclusive of the drawbridges,* (which will be hereafter described,) is 55 feet, the width at midships 45 feet, and at the ends 38 feet 6 inches. The engine house and cabins are 14 feet 6 inches wide, and of the whole length of the bridge. The roadways or decks are 11 feet wide in the clear at the ends, and 12 feet 9 inches wide in the middle; 2 feet 3 inches above the load water line at the ends, and 3 feet in the middle by a camber arch of 9 inches to carry off the water. The draught of water, when the bridge is full of heavy carriages, is rather under 2 feet 6 inches, and the clear depth of hold 4 feet 3 inches; and as the engine house, &c., rises 8 feet above the decks, the height from the hold to the roof is 12 feet 3 inches.

It will be observed from this description, and by a reference to the drawings, that the seat of the bridge in the water, or rather the line of floatation, is elliptic, and that the sides are curved vertically. (See Plate XXII.) The object

of these forms is to relieve the bridge as much as possible from the effect of the current, and to prevent the sudden stoppage of a wave, and the consequent spray over the side.

To avoid unnecessary weight and draught of water, it was a matter of much importance to keep down the size of the scantling, as well as weight of the framing ; yet from the great width and necessity for providing for occasional grounding, it was imperative to make the whole as stiff as possible. For the sake of lightness, all the planking and framing were of the best Quebec red pine, except those parts which formed the principal fastenings, including the two trussed frames along the bridge under the engine house partitions, and the diagonal braces or beams, which were of English oak, and iron kneed, and fastened with through bolts in the strongest manner. The engine house partitions, as well as the roof, are made moveable for the convenience of repairing or renewing the machinery. The roadways or decks have cross battens to prevent the horses' feet from sliding, and also for the better holding of a thin coat of sand and tar, as a more agreeable footing than wood. The fencing of the sides of the roadway is completed by carrying the timbers 3 feet 6 inches to 4 feet above the decks, and above that by the chains which suspend the draw-bridges forming a rail.

Proof of the great strength of the framing.

In proof of the great strength of the framing of this bridge, I cannot do better than relate a circumstance which occurred to it. The shipwright who built the bridge, being desirous of exhibiting so great a novelty, invited a party of friends to witness the launch, which went off with great spirit and more *wine* than was sufficient for the christening. The wine in this, as in many other cases, caused its votaries to be altogether oblivious of such unimportant matters as time and tide, which as they " wait for no man," so in this instance they ebbed faster than was perceived. It was the business of the builder to place the bridge in the basin of the new victualling yard, but a short distance from where the bridge was launched. With proper caution, the width of the entrance had been measured, and found sufficient for the bridge, but the measurement was taken at *high* water. The batter of the pier heads of course narrowed the width of the entrance as the tide ebbed, so that when the bridge was brought to the basin, the entrance was found just too narrow, and being caught on a rapidly falling tide, the bridge was literally suspended between earth and heaven for 8 or 10 hours till the return tide. It happened, most fortunately, that the bridge was caught so nearly in the middle of its

length that it balanced, otherwise it must have tipped endways and filled. I was not present at the accident, and concluded when I heard of it that, though not actually crushed, the framing must have suffered so much damage as to make a reconstruction necessary; but to my astonishment, as well as that of several ship builders whom I called in to aid me in the examination, nothing but a slight surface injury was observable, not a treenail having started or a fastening given way.

Since this the bridge has been frequently grounded, and found so stiff and stable, that it was not necessary to slacken a holding down bolt of the machinery.

Description of the drawbridges or platforms.

The drawbridges or platforms are of the same width as the roadways or decks, to each end of which they are hung by strong eyes of wrought iron, and a turn bolt of $1\frac{1}{2}$ inch diameter. Their length is 25 feet, they are fenced on each side by a strong trussed framing, and planked and battened, and sanded, to form a safe, level, and commodious communication between the landing place and the roadways of the bridge.

They are hung or suspended by two $\frac{3}{4}$ inch chains, one of which, as before stated, passes along the side of the bridge and forms a guard rail, and the other through the engine house, being there connected with a small purchase machine (shewn in Plate XXIII.). The chains, by passing over sheaves at the ends of the bridge and engine house, (as shewn,) and having their ends fastened to swivels attached to the sides of the drawbridges, not only suspend but also balance them, so that a very trifling power at the winch before named is sufficient to raise and lower them. When the bridge is in the act of crossing, the drawbridges form an angle with the water, as shewn by the general elevation at Plate XX., but of course, as the bridge approaches the landing places, the drawbridge by which the landing is to be made is lowered, and acts as a break to the machinery by its friction on the gravelled surface of the plane.

To obtain lightness, the scantling or framing of these platforms is Quebec red pine, planked with elm, the requisite strength being obtained by wrought iron suspension truss bars to each of the side pieces, as shewn on Plate XXI. These platforms are sufficiently strong to allow of the passage of a timber carriage of six tons' weight, which I have frequently witnessed, both fore and hind wheels being on the platform at the same time without causing the slightest derangement.

Cross galleries or stages at the ends of the engine house and cabins. Plates XX. and XXI.

To facilitate the passage from one roadway or deck to the other, there is a gallery or stage 6 feet 6 inches wide at the ends of the engine house or cabin, which forms an agreeable place for foot passengers, and the entrance to the cabin, where in rough weather shelter is obtained. These galleries are shewn in Plates XX. and XXI.

Cabin and engine house, boiler house, &c., &c. Plate XXIII.

At one end of the bridge is a spacious cabin, at the other end the boiler room, and between these is the engine room; all of which are shewn on the Plate. The roof is nearly flat, and covered with lead, 5 lbs. to the foot, laid on boarding fastened to a framing of wrought iron, which, as before stated, is made to take off easily. The side partitions of the engine and boiler rooms, and the framed pannelling which forms their external sides, are also made to shift easily, in case of repairs being wanted to the boilers or machinery.

Steam engines and machinery. Plate XXIII.

There are two steam engines, each having a cylinder of 19 inches diameter and 2 feet 6 inches stroke. They are common condensing steam engines, working at a pressure of $3\frac{1}{2}$ lbs. per inch in the boiler, and at an average speed of 35 strokes per minute. There is but one boiler, the external form of which will be readily understood by a reference to Plate XXIII. It has four flues through it, the bottom or fire flue being the whole width of the boiler, less the watercourses, which are four inches, and the three others are ranged side by side, with watercourses all round them of four inches. This arrangement gives 65 feet of flue in the boiler, and the construction is found convenient and economical of fuel. The sides and ends of the boiler are cased or clothed with sawdust 6 inches thick, retained by pannelled boarding, moveable in rabbeted cast iron carriage pieces, screw tapped to the boiler.

As fresh water is easily obtained on the eastern landing place, I have found it advantageous to feed the boiler with it, and instead of taking the feeding water from the hot well, it is procured from a tank which is supplied once or twice a day by a hose from the pipes on the shore. The waste steam being thrown into this tank, is sufficient to raise the water to 100°. The tank and arrangement of the feed pumps, &c., &c., are fully shewn in Plate XXIII.

The condensing water is of course taken from the river.

The engines are coupled at right angles by a continuous crank shaft, one end of which carries the pinion which drives the chain wheels, and the other end carries a bevelled wheel for driving the fly wheel, which, though not

necessary, is found to steady the working of the engines. This fly wheel, as will be seen by Plate XXIII., works *horizontally* under the roadway or deck of the bridge, where it was placed as being most out of the way, and is found to answer extremely well. The main pinion is 2 feet 10 inches diameter, and drives a wheel 7 feet 2 inches diameter, which is keyed on the shaft that carries the chain wheels. The chain wheels are 7 feet 6 inches diameter, keyed very firmly on the ends of a wrought iron shaft, which has its bearings on the tie beams of the bridge framing, and makes the distance between the wheels 10 feet 6 inches, and the distance from centre to centre of the two working or guide chains 11 feet. On the opposite side to the main gear wheel there is a break wheel of the same size, keyed to the shaft, which is furnished with a wrought iron clip or friction band. I have before stated that the periphery of each of the chain wheels is formed with cups gauged to the links of the chains, and that by this means the revolution of the wheels puts the bridge in motion in the opposite direction to the wheels, and as there can be no slipping of the chain, the velocity of the bridge is the same as that of the chain wheels, or about 320 feet per minute.

From this description it is evident that the periphery of the wheels will be liable to considerable wear by the weight and friction of the chains. This is provided for by casting the wearing parts in segments, and fixing new sets when necessary to the wheels.

The hand gear of the engines is managed in the most simple way, and the boiler so placed that one man can easily attend to the engines and fire. The signal for starting and stopping is given through speaking tubes, so placed that the conductor or deck-man can communicate instantly with the man at the engines.

At each end of the bridge, and in a line with the chain wheels, there are cast iron sheaves, 3 feet diameter, for the support and guidance of the chains through the bridge; and to prevent the accumulation of sea-weed and mud in the engine-room, the chains are cased off in their passage through the bridge.

Description of the chains, their balance weights, &c. Plates XIX. and XXIII.

The chains are of the common cable pattern, each 1 inch iron, and each link made to a gauge so as to fit the chain wheels without slipping. When the bridge is on either side of the river, the chains lie on its bed, and when the bridge is in the act of crossing, they of course form two arcs, as shewn by Plate XIX.

I have before stated, that instead of fixed moorings, the ends of the chains

are attached to weights suspended in shafts sunk at the heads of the landing places. These shafts are 20 feet deep and 16 feet square, and the weights are cast iron boxes loaded with five tons each, attached to the ends of the chains which enter the shafts over cast iron sheaves, 2 feet diameter, as shewn on Plate XIX.

Now it will be evident that when the bridge is at or near the middle of the river the chains form a double curve, and require to be longer than when the bridge is on either shore and they form but one curve, that is, rest on the bed of the river throughout. Supposing the chains to be fixed to the shore, it is, therefore, manifest that either they must be so short as to be unnecessarily strained, or so long as to allow the bridge to make lee way, and lie uncomfortably at the landing places. But by the plan of the balance weights here adopted, these difficulties are avoided, for as the bridge leaves the one shore the weights then rise, and the chains consequently lengthen to adjust themselves to an easy curve, and as it approaches the other shore, the balance weights on that side fall, the chains are gathered in or shortened, and the drawbridges thereby brought fair and end on to the landing plane; and, which is of the utmost importance, the chains have by this simple contrivance an uniform tension corresponding to the weight assigned to them, and which may be regulated at pleasure.

In the case under consideration, the weights rise and fall from 5 to 8 feet in each shaft, according as the weather and tide may happen.

Nature and extent of accommodation which the bridge affords.

It will be obvious from the descriptions already given, as well as from the accompanying drawings, that carriages and traffic of all kinds have a facility for entrance and exit from the roadways or decks of this kind of floating bridge infinitely greater than by any other plan now in use, whilst, from the simplicity of the landing-place, its easy slope, and direct or straight road from thence to and from the roadways of the bridge, carriages with six horses can drive on or off without even the removal of a horse or a passenger.

By the great breadth of the bridge its stability in the water is insured, and it is a rare thing to have even a sufficient degree of motion to attract the attention of the shyest horse, although, as before stated, the situation is so exposed that the ships of war, which lie in ordinary on each side of the site, frequently drag their moorings.

By employing chains as a guide from shore to shore, the passage by the bridge is rendered safe by night as well as by day, and in rough weather as well as fine; whilst, by the employment of them as a medium through which motion is conveyed to the bridge, a command is obtained over the motion which enables the man at the engine to start, stop, and move forward or back, with a facility and rapidity that could not be obtained by any other means. These advantages are found of the utmost value in the approach to and departure from the landing-places, the chains acting better than any warps, and superseding all necessity for men to attend that operation, as well as for a crew, such as steersman, look-out man, &c., &c., there being only two persons necessary for the working of this kind of bridge, viz., the man at the engine, and the man in charge of the drawbridges, and to direct the engine-man when to stop, and start. I have before stated, that the speed at which the bridge is worked across the river is, on an average, 320 feet per minute. This might be considerably increased if necessary, though I do not think it capable of being made equal to the speed of ordinary steam-boats worked by paddles. Still it must not be lost sight of, that in this, as in every other case of travelling, the proper measure for speed is the time taken to perform the journey, or as applied to the instance of crossing a river, the time which is occupied in the passage from the embarking at one shore to the disembarking at the other. Now, by the employment of chains the course is *direct*, the speed *uniform*, and may be maintained with safety to the shore approached; and the delay of backing, warping, &c., &c., which, on some ferries, takes as much time as crossing the river, is entirely got rid of.

In illustration of this, I need only mention, that the time occupied in crossing by this bridge is 7 minutes at low water, and 8 minutes at high water, (which is 320 feet per minute, the width at high water, as before stated, being 2550 feet,) the time being uniform, whether in rough or fair weather, night or day.

By the double roadway separated by the engine-house, &c., an opportunity is afforded for the separation of cattle, sheep, pigs, &c., from carriages and foot passengers.

As a criterion by which to judge of the capabilities of the bridge for accommodation, I would state, that I have seen in it at one time three carriages, each with four horses, one carriage with a pair of horses, seven saddle-horses, and 60

foot passengers, and still there was nothing like crowding or discomfort. Though the exposure of the site is such that the sea frequently breaks over the funnel of the engines, I have never yet known the passengers of the Devonport and Falmouth mail, or of the other coaches, which regularly cross it twice a-day, leave their seats, even from the top of the coach. Of course, in such cases, the roadway on the lee side is chiefly used.

Regulations and government of the bridge.

The bridge crosses the river *four* times an hour, viz., it leaves the landing-place on the east side at the half-hours, and the landing-place on the west side at the intervening quarters. The time of crossing, as before stated, is, on an average of high and low water, $7\frac{1}{2}$ minutes, and therefore the stoppage on each landing-place is $7\frac{1}{2}$ minutes, making up the quarter of an hour.

The hours of working are from 6 till 10 o'clock in the summer, and from 7 till 9 in the winter, but the Directors allow the public the accommodation of all the intermediate hours on payment of additional tolls and proper notice.

The tolls are let to a yearly tenant free of all expenses except collection, on the covenant that the bridge shall work agreeably to the regulations and hours before described; and for his own interest, the tenant enforces from the servants of the Company the rigid performance of the regulations by ringing the toll-house bell for the starting of the bridge from each side.

During the four years that this bridge has been established, it has not been interrupted in its regular course of working for an hour at any one time, and even that not more than twice or three times, although in this period, as is well known, we have had two very rough winters. We have also had two or three breakages of the chains from defective welds; these, however, only occasioned the delay of a few minutes, as the plan is to continue working on one chain till night, when in the space of an hour the broken ends can be picked up by a grapnel from the bridge and shackled together.

It has never happened that these bridges have broken adrift by the separation of both chains at the same time; and hence will be seen the propriety of using two chains in all cases, each chain being sufficient to hold the bridge.

I cannot, perhaps, give more satisfactory evidence as to the safety, convenience, and fitness of these bridges for crossing estuaries where a fixed bridge cannot be obtained, than by referring to the examination of George Louis, Esq.,

the superintendent of mail coaches, before the committee of the House of Commons which sat on the Post Office affairs in the session of 1835 and 1836. After pointing out the advantages of such a bridge over the Severn at either the new or old passage, and mentioning the safety and regularity of the one established at Torpoint, he says, "If such a bridge could be made across the Severn, it would render the passage *sure*."

Expenditure or cost of the works, disbursements, income, &c., &c.

I should premise that there are two bridges which work, according to the regulations before described, alternate months; each bridge has its own chains, and they are fitted to be perfectly independent of each other. The advantages of this arrangement will be obvious, affording as it does the opportunity for periodical examination and timely repair, as well as the ready means of providing against the interruption of the traffic by reason of breakage of machinery or accident to the bridge for the time in work. It is also found to be economical, as the interest on the additional capital is more than saved by the facility afforded for repairs, and the diminished wear and tear arising from a regular examination of, and immediate attention to, trifling and incidental derangements in the machinery, &c.

During the first two years there was but one bridge; and a comparison of the disbursements then with those of the last two years, or since the second bridge has been established, enables me to speak from facts on this point.

The cost of the first bridge, with its machinery and chains, was £3222; that of the second was £3316. The cost of the landing planes, shafts, and balance weights, £1530; of engineering and law expenses about £1000; making the whole expenditure about £9068. The yearly charges or disbursements are as follow;

WAGES.

	£	s.	d.	£	s.	d.
Chief engine man 31*s.* 6*d.* per week, per annum	81	18	0			
Assistant ditto, 25*s.* per week, per annum	65	0	0			
Man to attend to drawbridges and roadways of bridge at 20*s.* per week	52	0	0			
Two men as occasional labourers in smith's shops, and to assist engine men in the repairs, get coals on board, light lamps, &c., each 12*s.* per week	62	8	0			
				261	6	0

	£	s.	d.	£	s.	d.
Brought over				261	6	0
FUEL, ETC.						
The consumption of coals for the year ending Christmas last was 308 tons, (or rather more than 16½ cwt. a day,) the average price of which in the store was 18*s*. 6*d*. per ton, or	284	18	0			
Oil for machinery and lamps, tallow, hemp, &c., &c., per annum	28	12	0			
				313	10	0
REPAIRS.						
Three sets of cast iron segments for chain wheels, weighing 26 cwt., or the three sets 78 cwt., at 14*s*., fitted	54	12	0			
Two sets and a half of fire bars a year, or in all 22½ cwt., at 9*s*.	10	2	6			
Incidental repairs for the year ending Christmas 1837, being for painting, carpenter's work, iron and brass work, and labour, beyond that performed by the servants of the company, and included in account for wages	67	12	0			
	132	6	6			
CREDITOR.						
Old segments and fire bars, about 90 cwt., at 3*s*. 6*d*.	15	15	0			
				116	11	6
Total yearly charges				£691	7	6

As yet we have no means of fixing with any precision the sum which should be reserved yearly as a rebuilding fund, for the bridges and machinery are still as good as new, and the chains, which at first I expected from the great depth of the river would be an expensive item in the repairs, are scarcely at all worn.

The income of the ferry for the year ending 11th April, 1834, when the bridge was opened to the public, was £930, whilst for the year now just ending the tolls are let at £2000 over and above the cost of collecting, being an increase in four years of £1070, that is, the tolls have already more than doubled. This is the strongest evidence than can be adduced in proof of the great accommodation which the bridge affords.

General and concluding remarks.

To have gone into the particular construction and arrangement of the machinery and scantling of the framing of the bridge, would have extended this paper to a great length, and it would also

have rendered many plates of illustrative drawings necessary. This being the case, I thought it better to reserve such details for another communication, should it be desired, than to be brief where brevity might only lead to error, for I need hardly remark to the practical engineer, that nothing is more calculated to mislead than incomplete detailed drawings, &c., of machinery and engine work.

Local circumstances would also so often interfere to modify the details of such a work, that after all, they must be in a great measure left to the judgment of the engineer.

It may be thought that I should have contrasted this kind of floating bridge with the swing bridges, boat bridges, &c., &c., of the continent, and with the steam boats employed on some of the great ferries of our own island, but I felt that I might have subjected myself to the charge of blind partiality, so often applied, and frequently with justice, to inventors. I therefore intentionally refrain from such comparisons, deeming them less necessary from the circumstance that the members of the Institution, for which this communication is designed, will be the best discerners of the comparative merits of these several plans, as well as of the claims of the one here described to the rank of a useful invention, in a country like ours, having numerous estuaries and narrow seas, where the importance of the navigation or the great first cost will not admit of a fixed bridge, though the population of the district and general traffic of the country suffer from the want of a better communication than ordinary ferries can afford.

In conclusion, I have only further to state, that whilst the bridge here described was in construction, one was established at Saltash, (higher up the Tamar,) and still more recently, a similar bridge (though differing in the arrangement of its details to suit the locality) has been established under my directions at Southampton, across the Itchen, which is, at the site of the bridge, 1400 feet wide at high water, and is crossed 8 times an hour. This bridge is found so formidable a rival to the *fixed* bridge a little higher up the same river at Northham, as to have drawn off nearly all the travelling, the trifling saving in distance into the Portsmouth, &c., road which the floating bridge and new road effect, being sufficient to induce all the stage-coaches and mails, amounting to 11 a day, and general travelling, to use it in preference. This is the most convincing proof that the accommodation is regular and commodious. Already

the tolls of this bridge have been let for £2500 per annum, although the work has not been finished 18 months, and the only traffic on the ferry previously to the establishment of the bridge was foot passengers, and produced only £400 a year.

JAMES M. RENDEL.

34, Great George Street, Westminster,
Feb. 1838.

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Bevan, John, 19, Buckingham Street.
Boorer, John, 3, Lower George Street, Sloane Square.
Borthwick, M. A., 23, Great George Street.
Bourns, Charles, Cardiff.
Braidwood, James, 68, Watling Street.
Braithwaite, Frederick, New Road.
Bramah, Francis, Jun., Pimlico.
Brandreth, Captain, R.E., Admiralty.
Brine, James Augustus.
Bull, William, Hostingley House, Wakefield.
Capper, C. H., Birmingham.
Carnegie, W. F. Lindsay.
Carpmael, William, 4, Old Square, Lincoln's Inn.
Cayley, Sir George, 48, Albemarle Street.
Combe, James, Dorking.
Comrie, Alexander, 23, Fludyer Street.
Cottam, George, Winsley Street.
Cottam, George Hallen, Winsley Street.
Crane, George, Yniscedwyn, Swansea.
Crawshay, William, 39, Upper Thames Street.
Cubitt, Lewis, Gray's Inn Road.
Cubitt, William, Gray's Inn Road.
Davidson, John Rankin, Stone, Staffordshire.
Davison, Robert, Brick Lane.
Dawson, Capt. R.E., 9, Somerset Place.
Denison, Lieut. R.E., Woolwich.

Dent, Edward John, 85, Strand.
Deville, James, 367, Strand.
Donkin, Bryan, Jun., 6, Paragon.
Drewry, Charles S., 77, Chancery Lane.
Dundas, John F., Dumfries.
English, Henry, 12, Gough Square.
Errington, J. E.
Evans, Thomas, Dowlais.
Francis, Charles L., South Lambeth.
Freeman, William, Millbank Street.
Frome, Lieut. R.E., Chatham.
Green, Joseph, Exeter.
Guest, Sir Josiah John, Bart., M.P., F.R.S., F.G.S., F.H.S., 13, Grosvenor Square.
Gutch, George, Bridge House, Harrow Road.
Hallen, Benjamin, Winsley Street, Oxford Street.
Handley, Henry, M.P., 30, Pall Mall.
Hardie, Thomas Girdwood, Blaenavon.
Harness, Lieut. R.E., Woolwich.
Heathcoat, John, M.P., 8, Wood Street.
Hemming, Samuel, Wolston, near Coventry.
Henderson, Lieut. Colonel, Wandsworth.
Henderson, Peter, Cardiff.
Hennet, George, 16, Duke Street.
Henry, David, Dublin.
Holtzapffel, Charles, 64, Charing Cross.
Horne, James, F.R.S., M.R.I.A., Clapham Common.
Houghton, Dugdale, Edgebaston, near Birmingham.
Howard, Thomas, 7, Tokenhouse Yard.
Howell, James, 1, Vincent Square.
Hunter, James, Bow, Middlesex.
Inman, William Southcote, 57, Pall Mall.
Johnson, John, Grosvenor Wharf, Millbank.
Jones, John Edward, 22, Strand.
Jopling, Joseph.
Kendall, Henry E., Jun., F.S.A., A.I.B.A., 23, Hunter Street.
Kennedy, Henry, New Street, Kennington.
King, Nicholas, 2, Riches Court, Lime Street.
Knight, Samuel J., Pimlico.
Lawrie, Alexander.
Leahy, Patrick, County Court, Cork.

Leather, John Thomas, Sheffield.
M'Intosh, David, 39, Bloomsbury Square.
Macquiston, Peter, Glasgow.
Manby, Charles, 9, John Street, Adelphi.
Marshall, James Garth, 41, Upper Grosvenor Street.
Martin, Henry, 49, Leadenhall Street.
Massie, James J., Aberdeen.
May, Charles, 7, Cowper Street, City Road.
Milner, John, New Road.
Mitchell, Alexander, Belfast.
Moorsom, Captain, Railway Office, Cheltenham.
Moreland, Richard, 149, Old Street, St. Luke's.
Moseley, William, 53, Great Ormond Street.
Murray, Andrew, Millwall.
Mushet, David, Coleford.
Newton, William, 66, Chancery Lane.
Nichols, Nathaniel, Bethlem.
Nicholson, Robert, Newcastle.
Nicholson, William W., Gray's Inn Road.
Oldham, John, 9, Whitehall Place.
Paine, John Davies, 57, Lincoln's Inn Fields.
Parsons, William, Leicester.
Pellatt, Apsley, Holland Street, Blackfriars.
Penn, John, Jun., Greenwich.
Peppercorne, Frederick S., 15, Buckingham Street.
Pim, James, Jun., Dublin.
Poole, Moses, 4, Old Square, Lincoln's Inn.
Reid, Colonel.
Renton, A. H., Pimlico.
Reynolds, John.
Richards, Josiah, Rhymney Works, Monmouthshire.
Rickman, William, Duke Street.
Robe, Captain R.E. Ordnance Map Office, Tower.
Rowles, Henry, 15, Stratton Street.
Saunders, William Wilson, East Hill, Wandsworth.
Seaward, Samuel, Canal Iron Works, Limehouse.
Simms, William, F.R.A.S., 136, Fleet Street.
Smith, Capt. W. T., M.E., Madras.
Spearman, J. M.
Stansfield, John, Woolwich.
Steele, Thomas, Ennis.

Stephenson, R. M., 105, Upper Thames Street.
Stutely, Martin John, John Street, Adelphi.
Sylvester, John, 85, Great Russell Street.
Sylvester, Professor, University College.
Taylor, Thomas F., 7, Salisbury Street.
Thompson, Alfred, Eccleston Street, Pimlico.
Thompson, James, Glasgow.
Townshend, Richard, New Ormond Street.
Treacy, W. A., 9, Whitehall Place.
Treherne, Edmund, 11, South Molton Street.
Tremenhere, Lieut. Bengal Engineers, 33, Somerset Street.
Vint, Henry, Lexden.
Vulliamy, Benjamin Louis, 68, Pall Mall.
Walker, John, Maidstone.
Waterhouse, John, Halifax.
Watkins, Francis, 5, Charing Cross.
Wells, Colonel, R.E., 85, Pall Mall.
White, George Frederick, Millbank Street.
Whitwell, Stedman, Kentish Town.
Williams, Charles Wye.
Wright, John.

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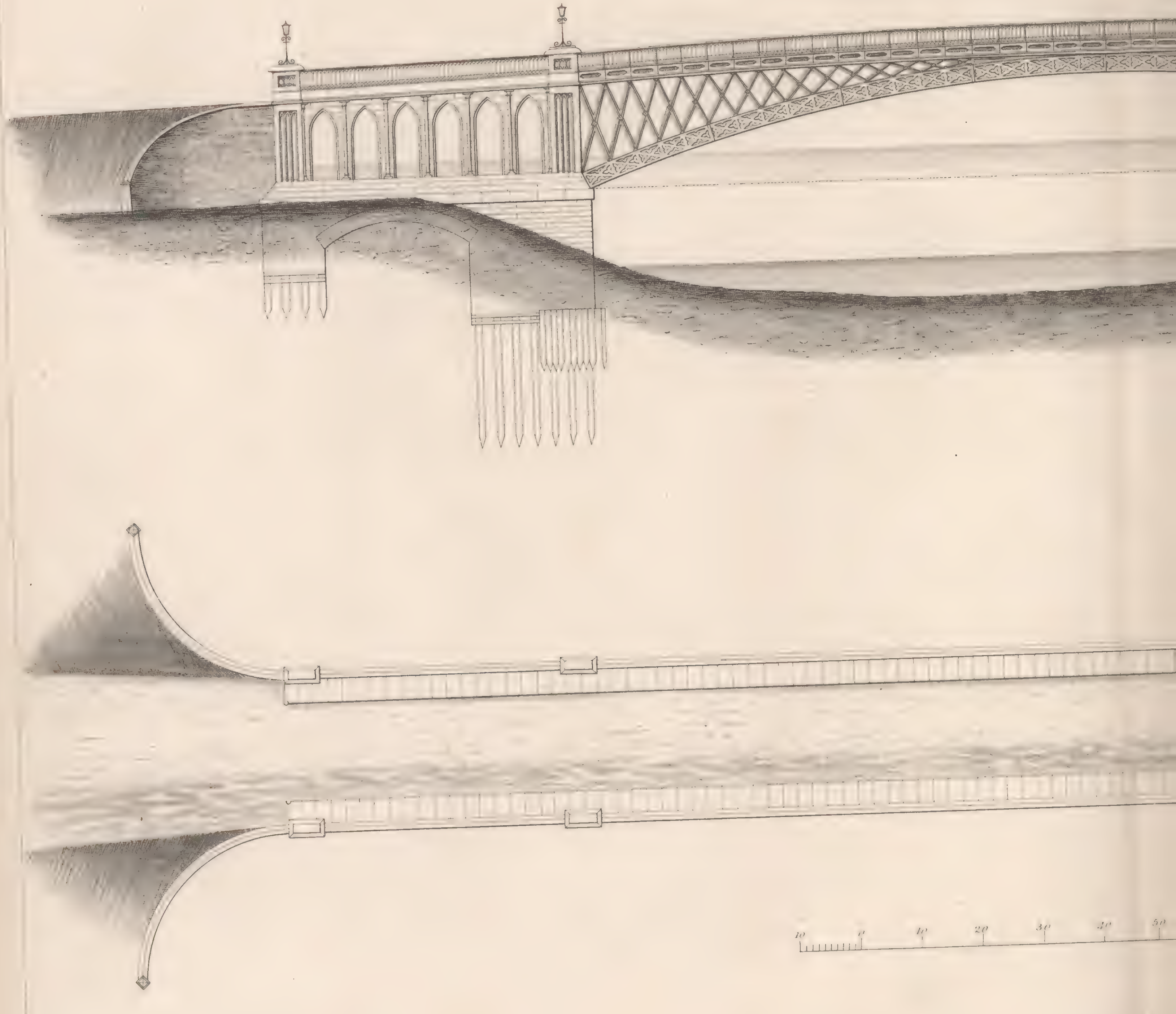

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John Weale

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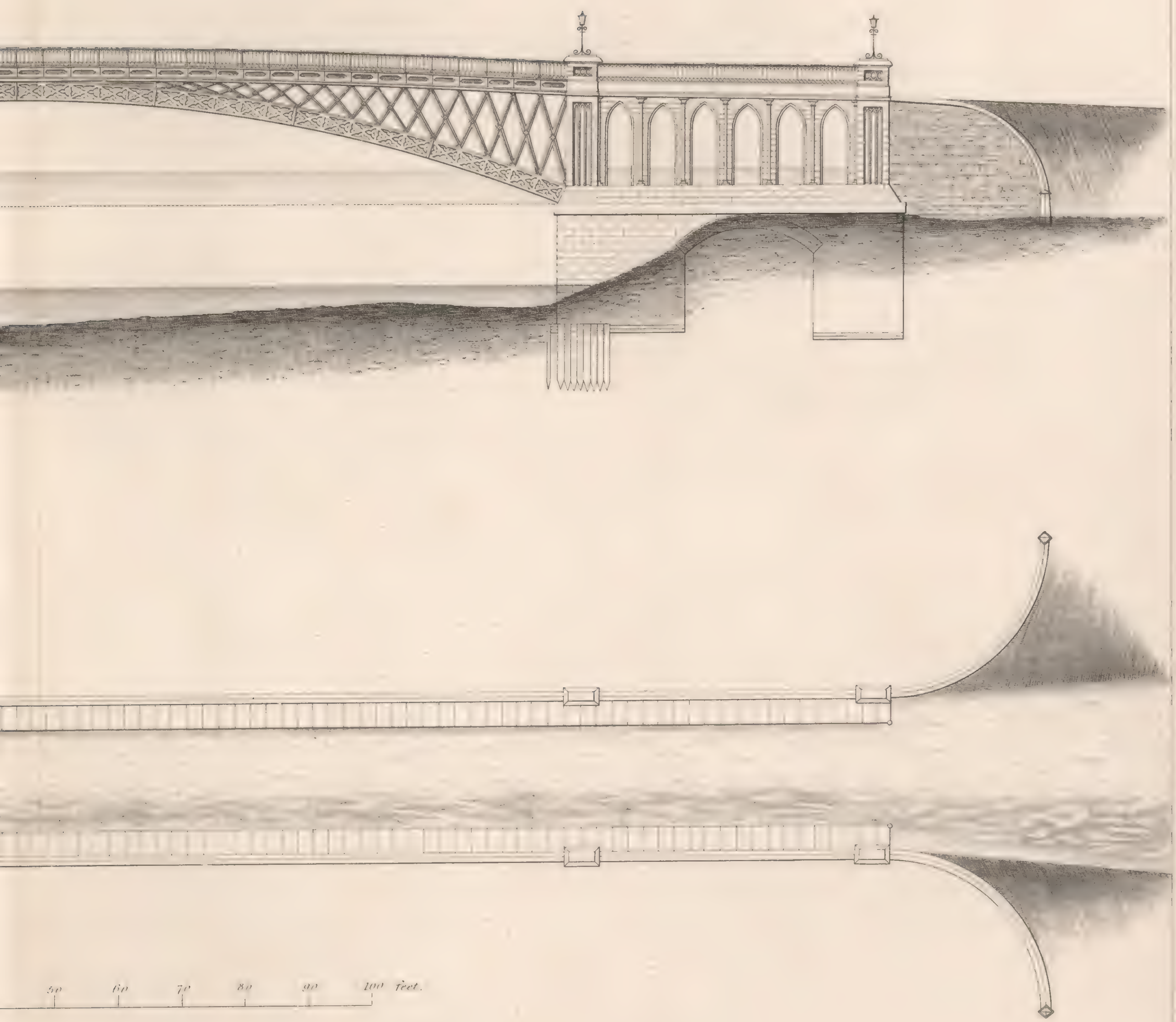

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TEWKESBURY

DETAIL

Fig. 4.

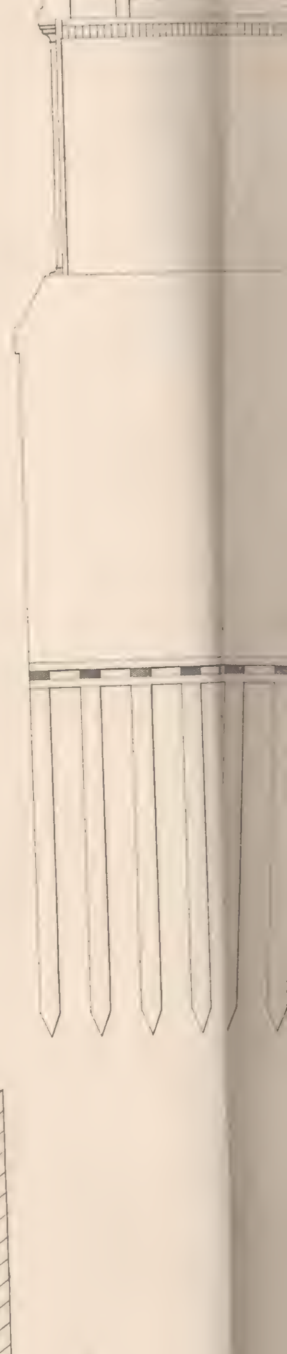


Fig. 1

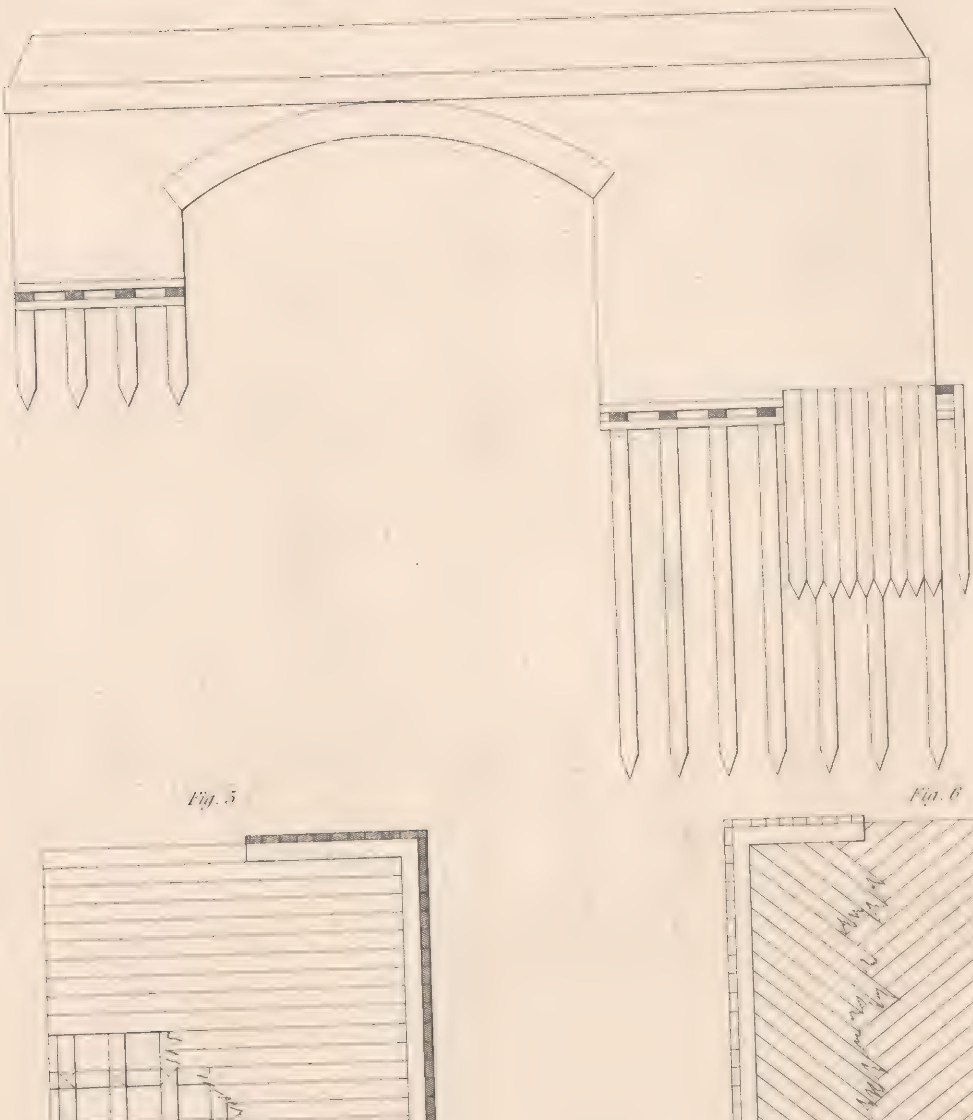


Fig. 5

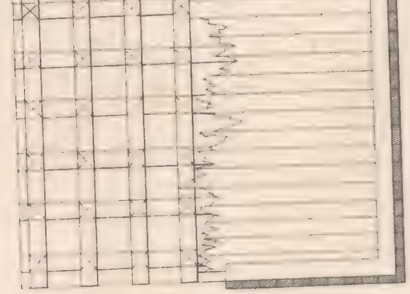
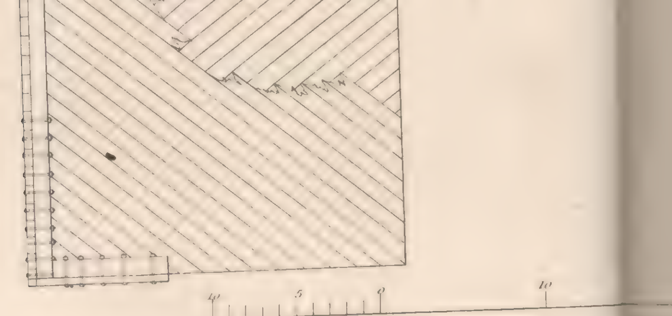


Fig. 6



del.

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DETAILS

Fig. 1

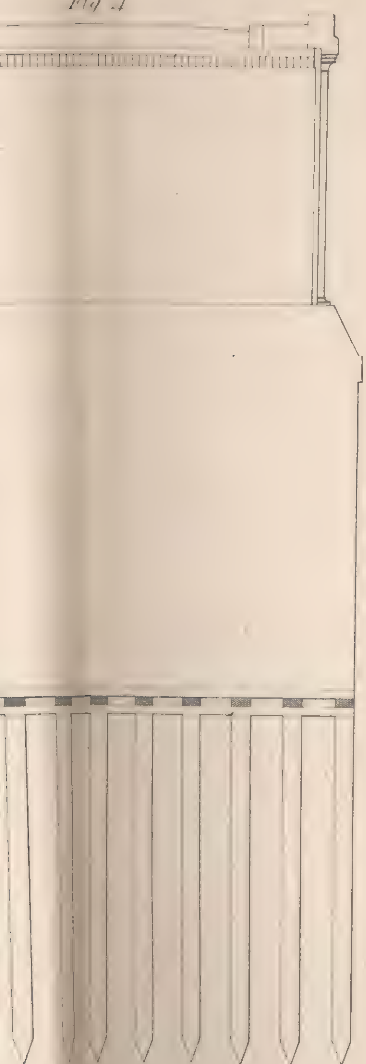


Fig. 2

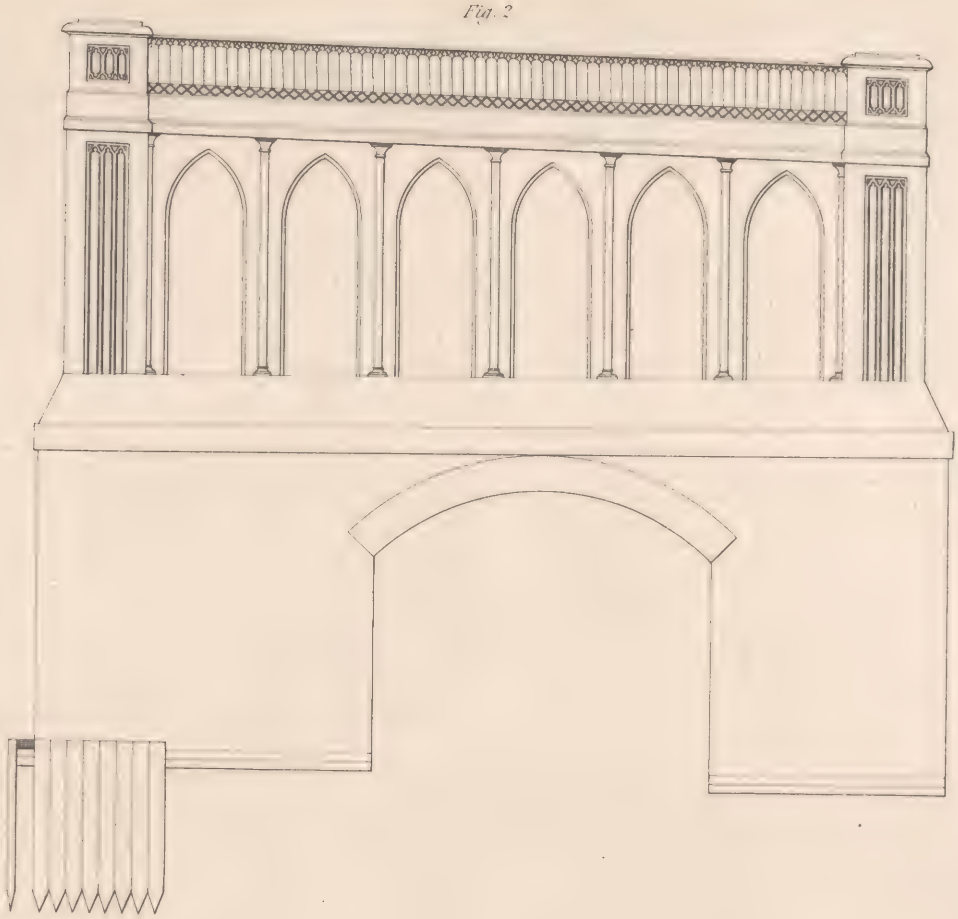
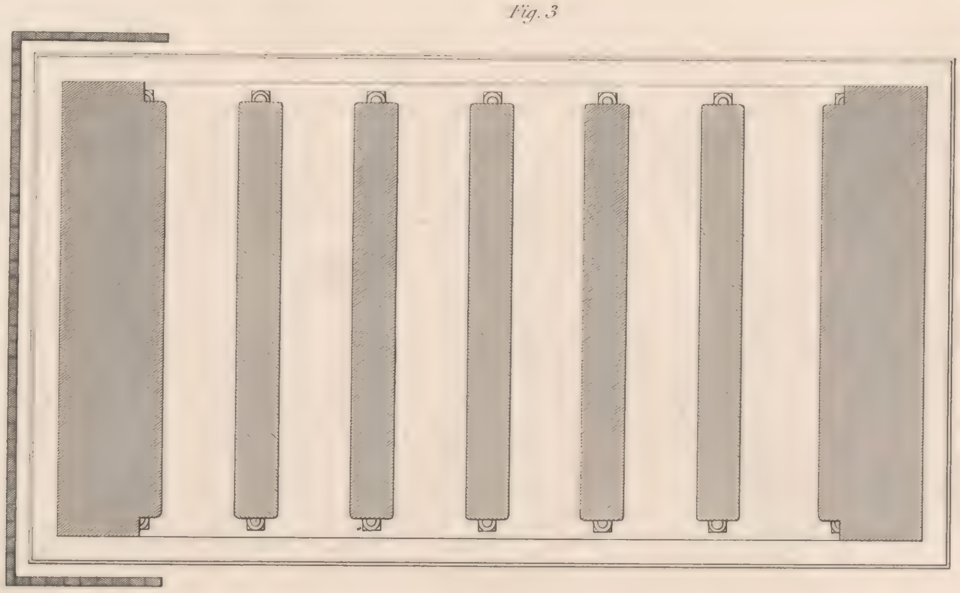


Fig. 3



20 30 40 50 Feet

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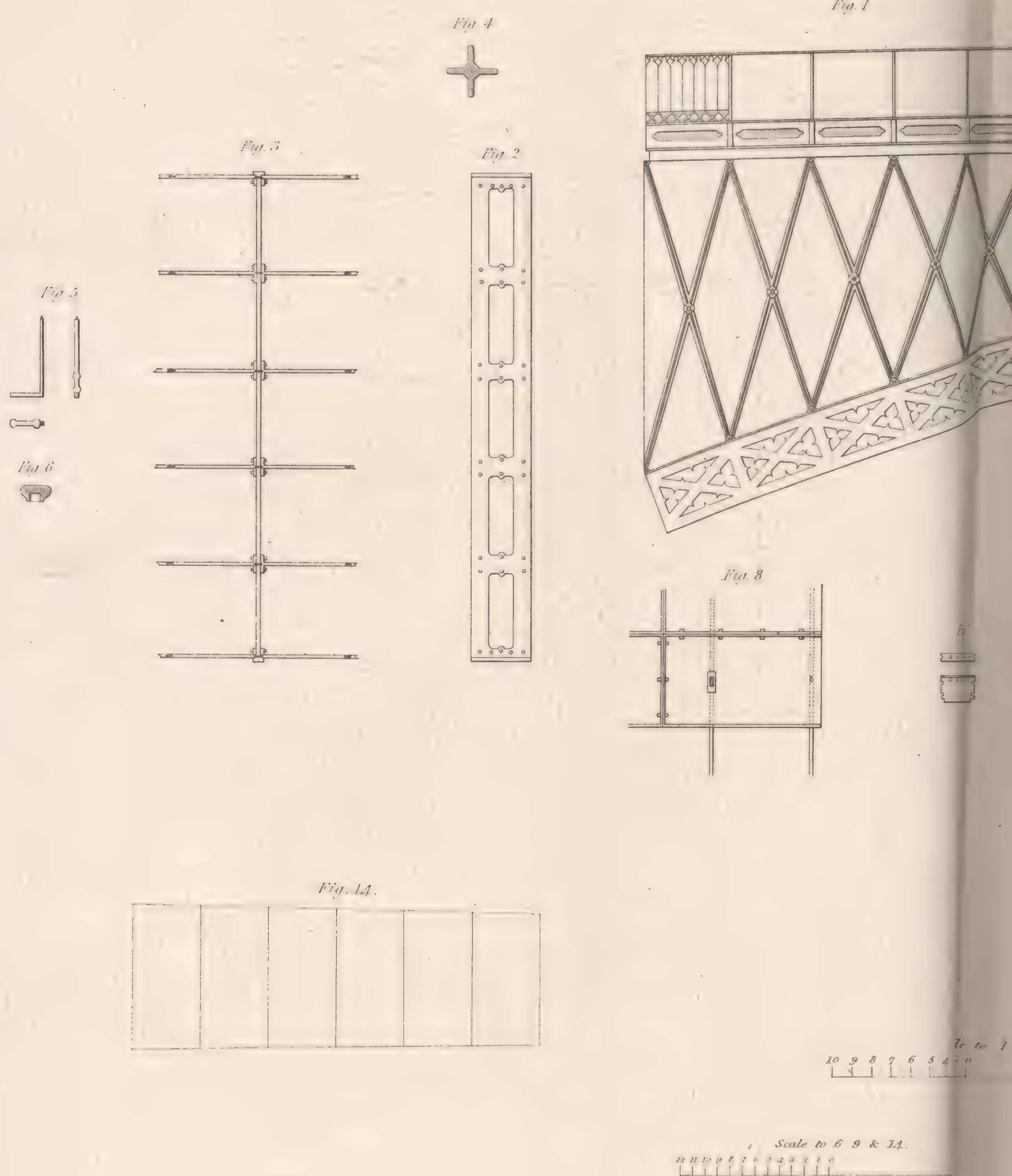

T. Telford del.

ESBURY BRIDGE.

DETAILS.

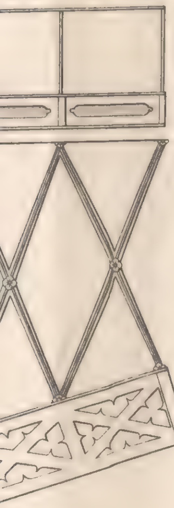

Fig. 9

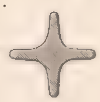

Fig. 11

Fig. 12

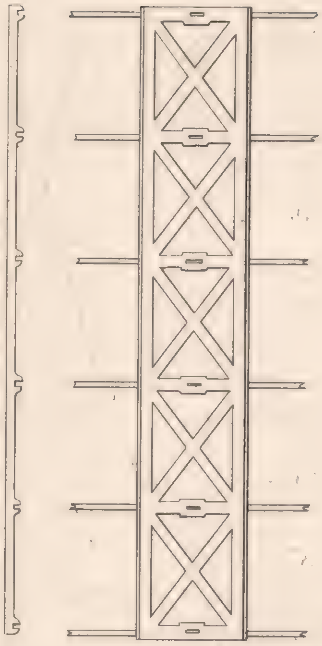

Fig. 10

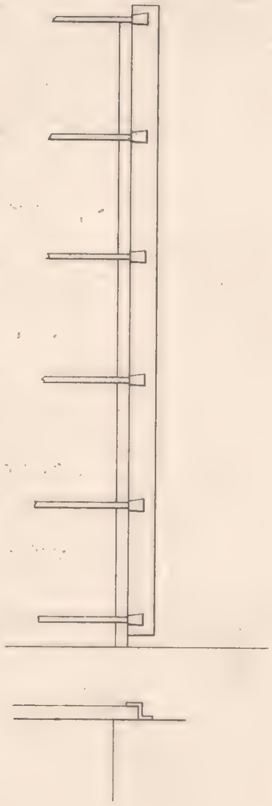

Fig. 13

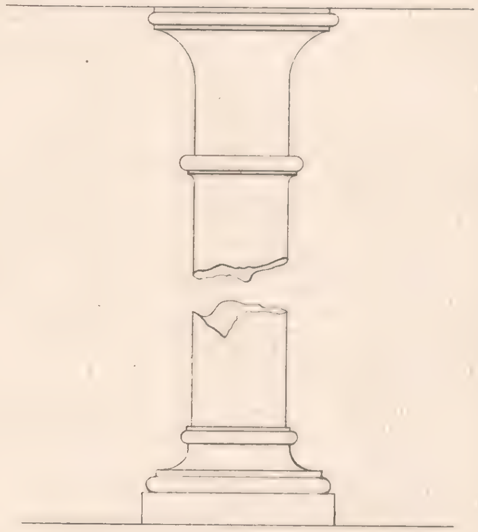

Fig. 7

Scale to 1. 2. 3. 5. 7. 8. 10. 11. & 12.

5 4 3 2 1 0 10 20 Feet

1 Foot

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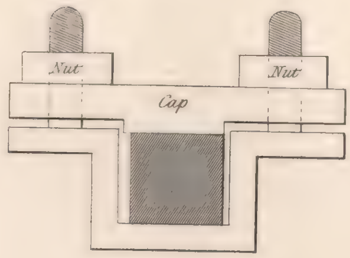
Fig. 1



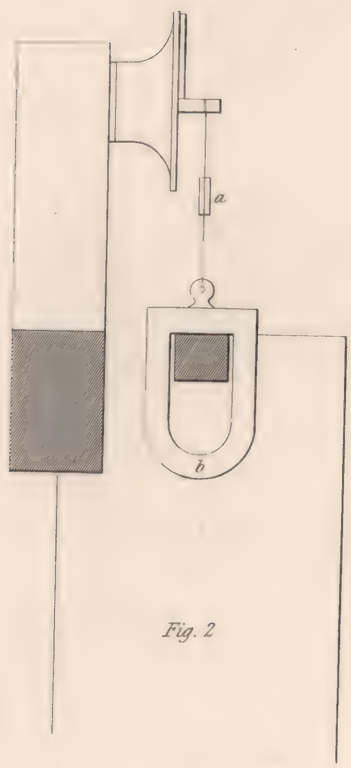


Fig. 2

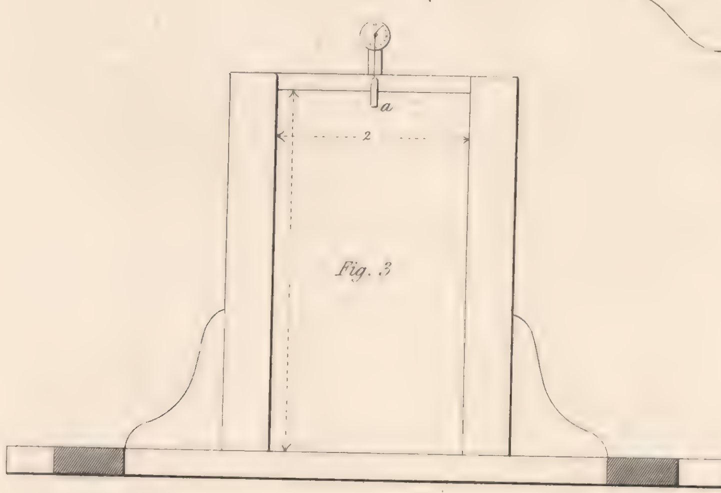


Fig. 3

Fig. 4. Huel Towan, Wilson's Engine

(Steam in the Boiler 61·8 lbs on the Square inch.)

Fig. 5. Binner Downs, Swan's Engine

(Steam in the Boiler 74·78 lbs on the Square

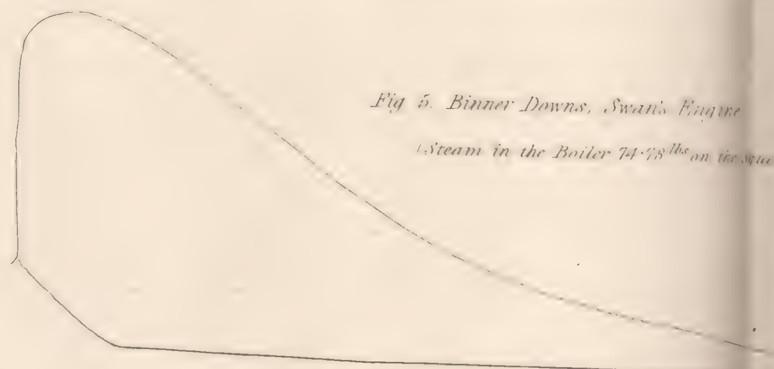


Fig. 6. Binner Downs, Swan's Engine

(Steam in the Boiler 58 lbs on the Square inch.

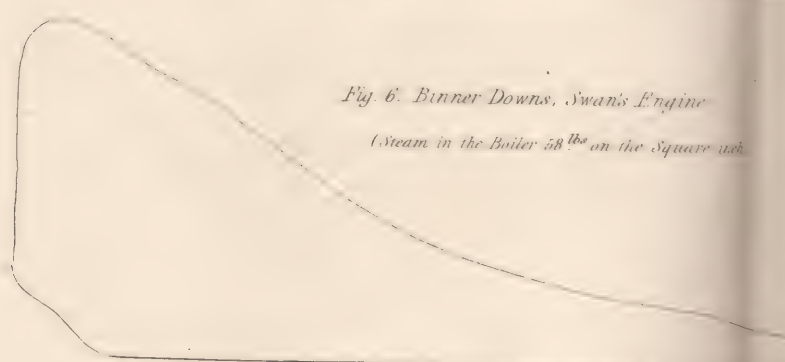
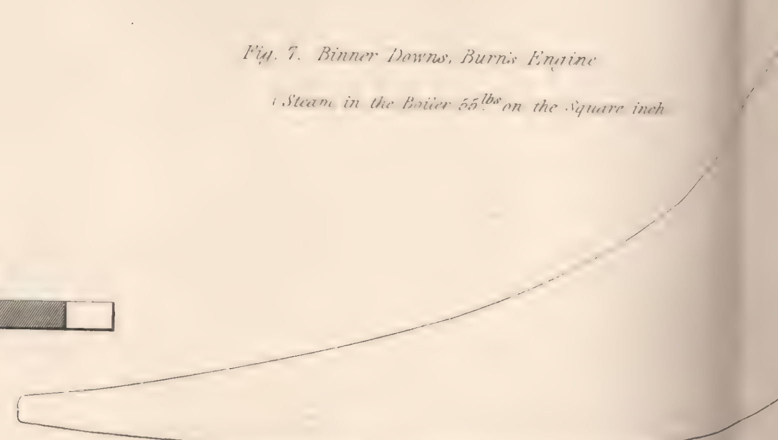


Fig. 7. Binner Downs, Burn's Engine

(Steam in the Boiler 55 lbs on the Square inch.



a. Weight to keep the thread stretched.

b. Hook for scale.

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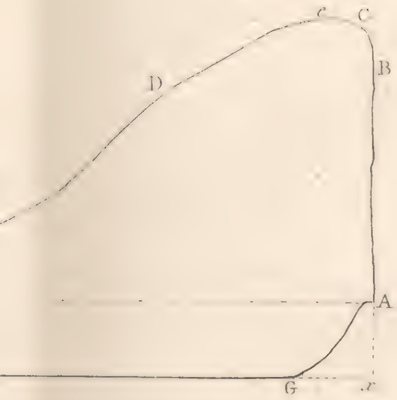
J. Henwood }

John Weale



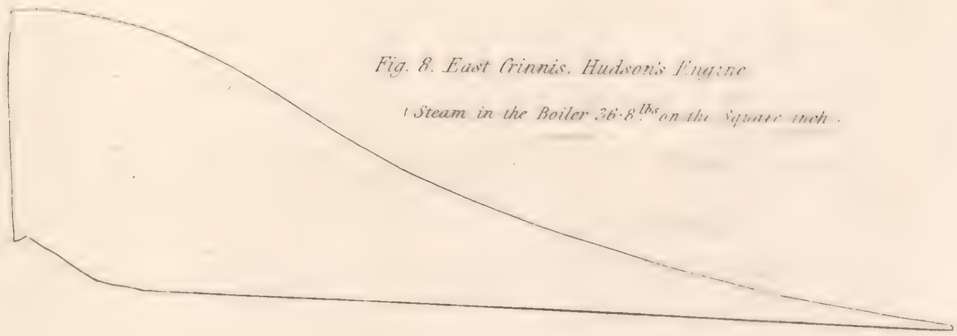


Fig. 8. East Crinnis, Hudson's Engine

(Steam in the Boiler 36·8.lbs on the Square inch.)

gine

n the Square inch)

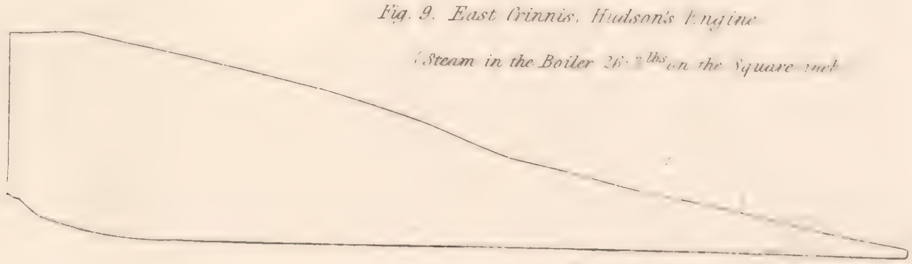


Fig. 9. East Crinnis, Hudson's Engine

(Steam in the Boiler 26·3 lbs on the Square inch)

inch)

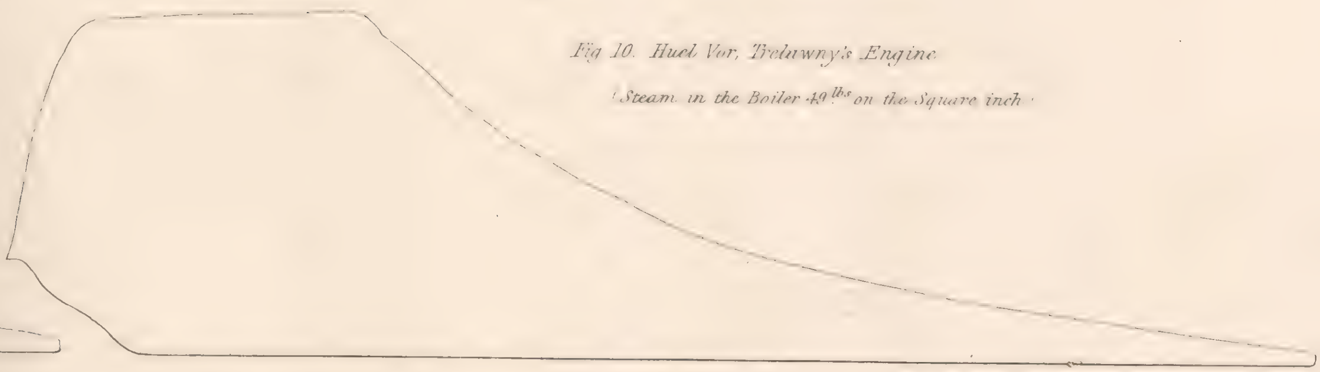


Fig. 10. Huel Vor, Trelawny's Engine

(Steam in the Boiler 49.lbs on the Square inch.)

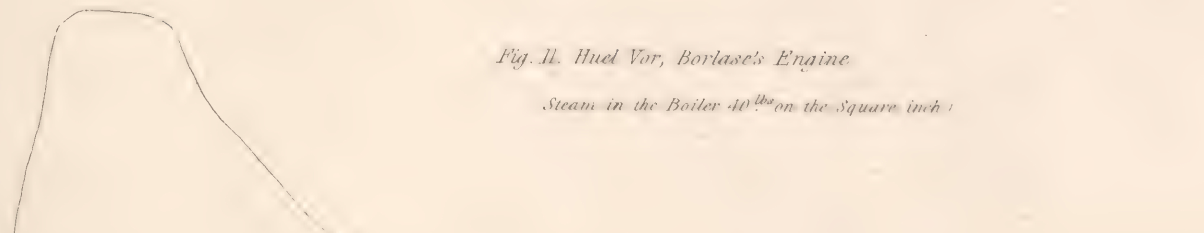
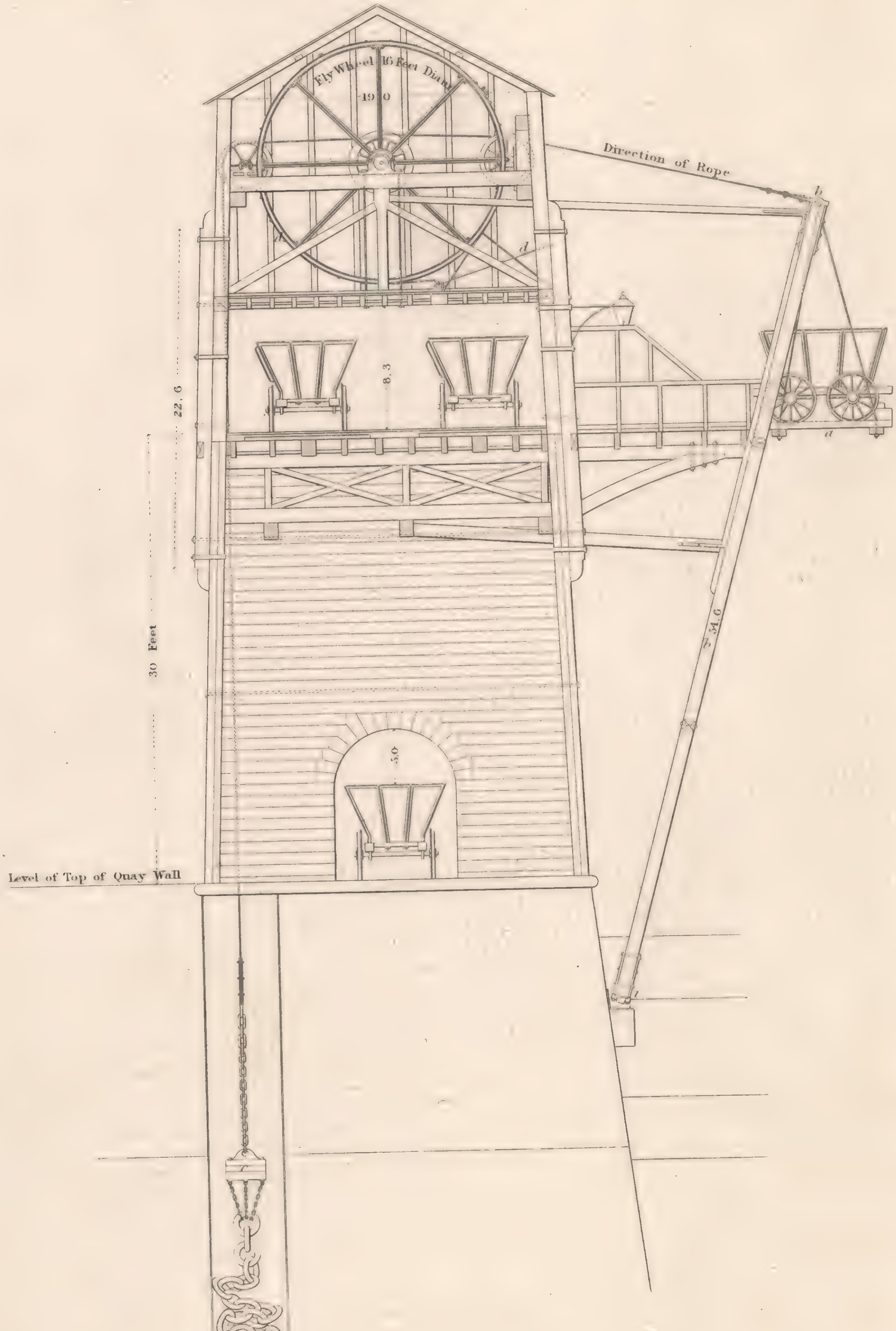


Fig. 11. Huel Vor, Borlase's Engine

(Steam in the Boiler 40.lbs on the Square inch.)

FIG. 1.

Longitudinal Section, shewing Machinery, mode of fastening the Frame work &c.



Back View shewing
when the

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FIG. 2.

View shewing the Counterbalance Weight when the Waggon is Lowered.

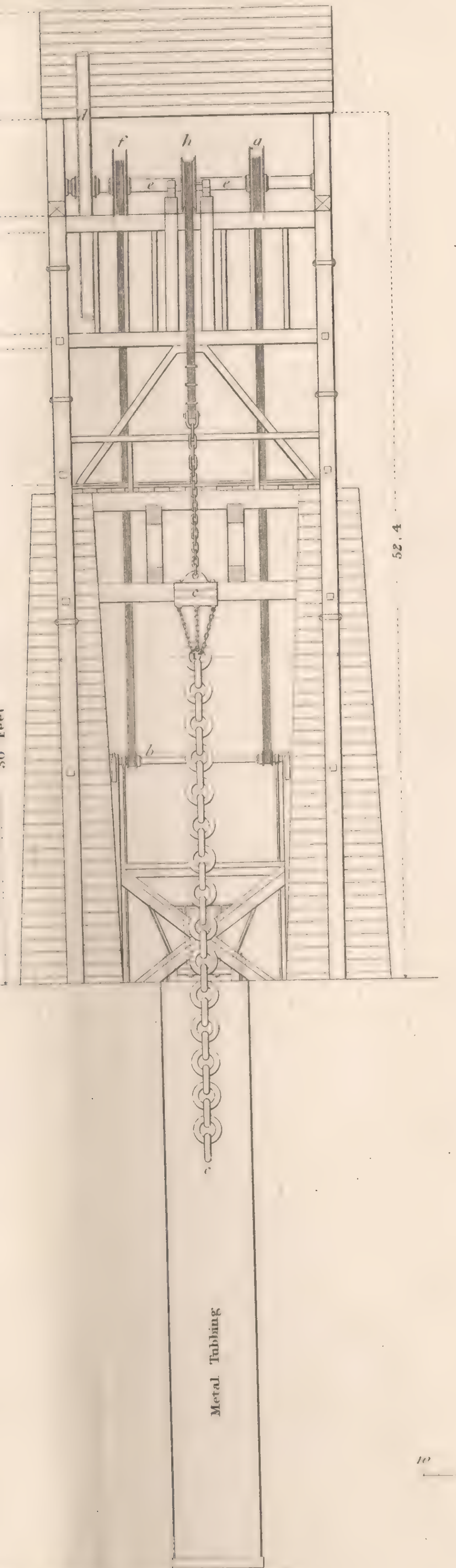
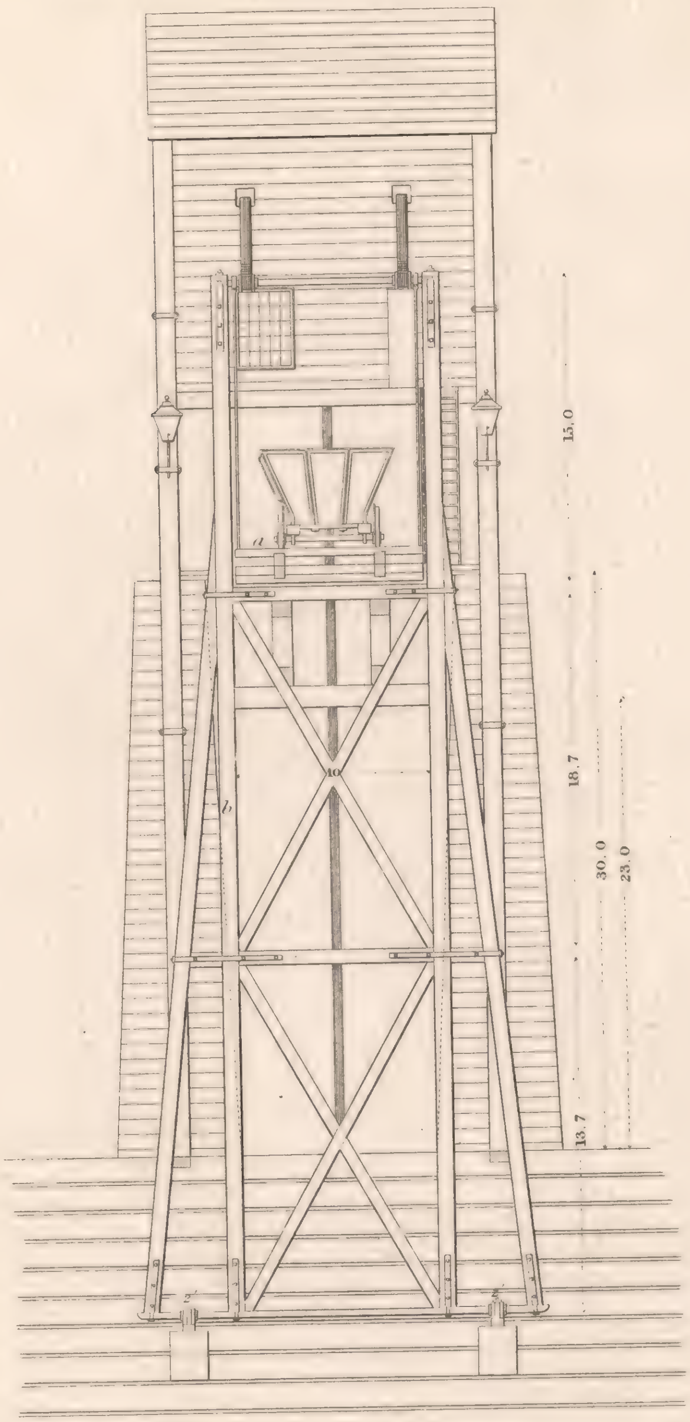


FIG. 3.

Front View shewing the Vibrating Frame.



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J.W. Lowry, Sculp.

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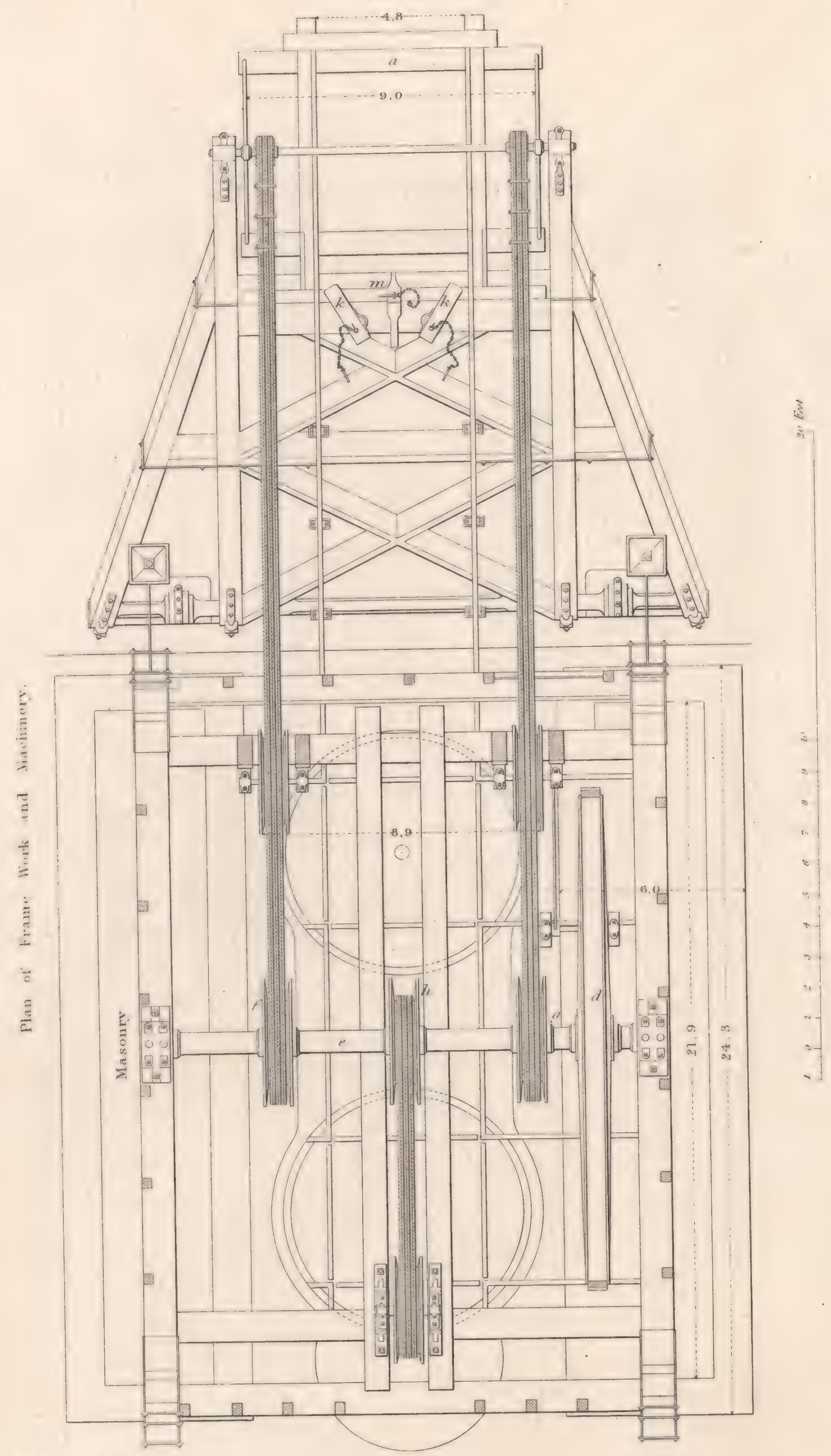
FIG. 4.



Plan of Frame Work and Machinery.

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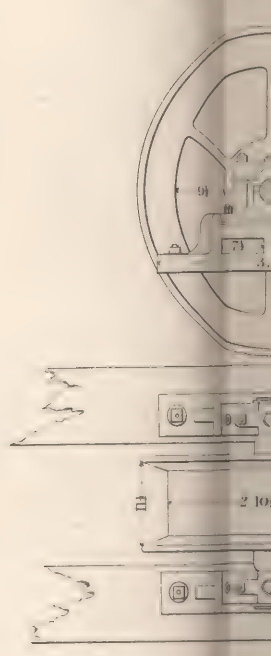
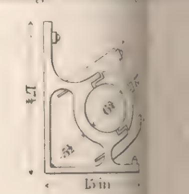
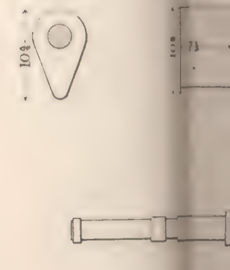
Counterbalance



Carriage for Vibrating frame.



Cab. Side.



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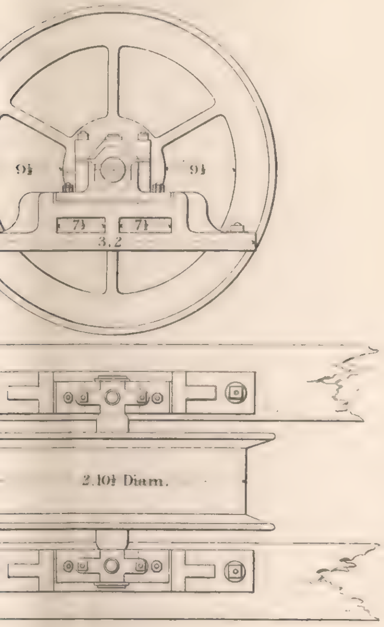
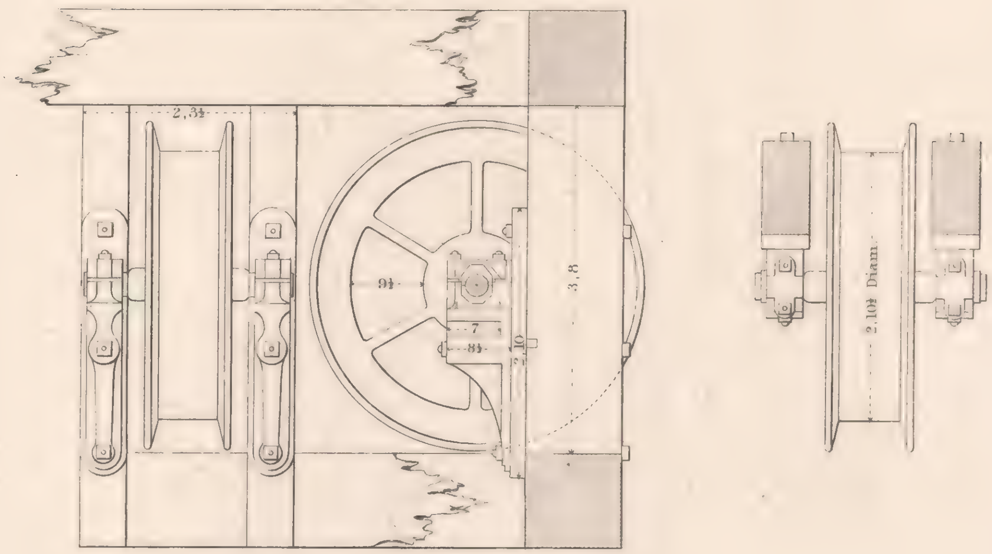
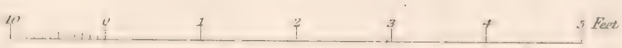
erbalance Weight Sheaves.



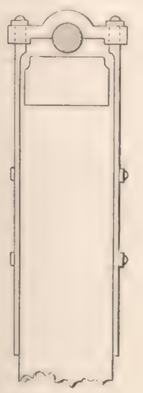
Front Sheaves for conveying the Ropes.



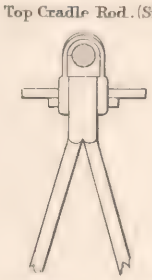


rating Frame.

Top of Vibrating Frame Side View.

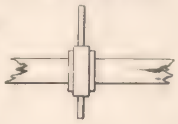


Top Cradle Rod. (Side)

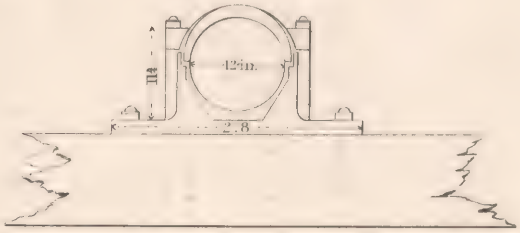


Straps ..... 3.6 Long
Nuts .... 1½ × 1 in.
Bolts ...... ½

Top of Cradle Rod.

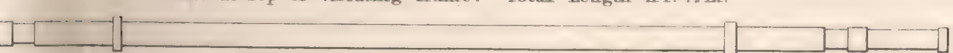


Carriage for Main Shaft.



Cab.

Shaft at Top of Vibrating frame. Total Length 11 Ft 7½ in.



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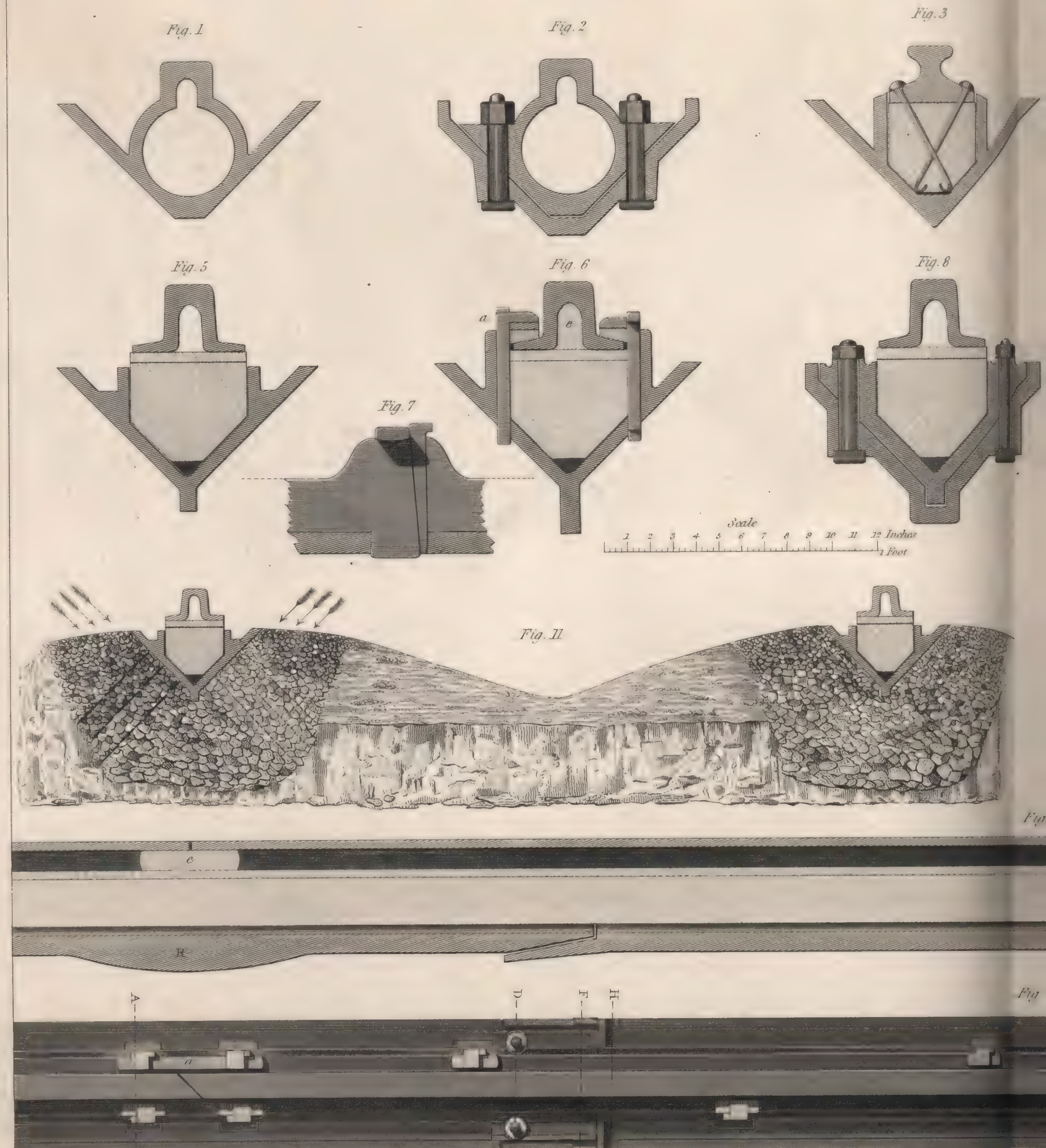
J.W. Lowry Sculp

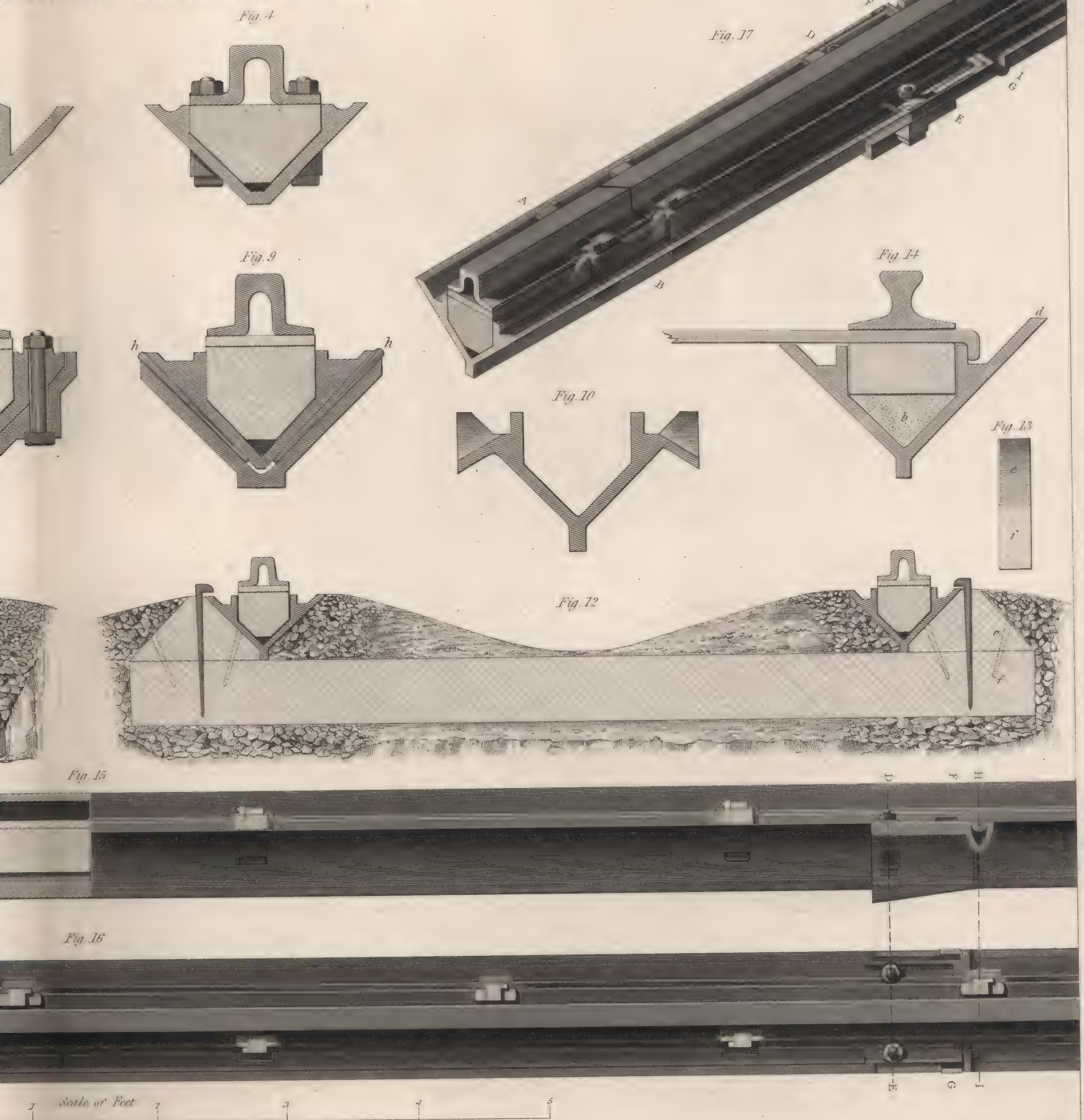
REYNOLDS ON RAILWAYS



J Reynolds del.

Plate VII.

LWAYS OF CONTINUOUS BEARING.



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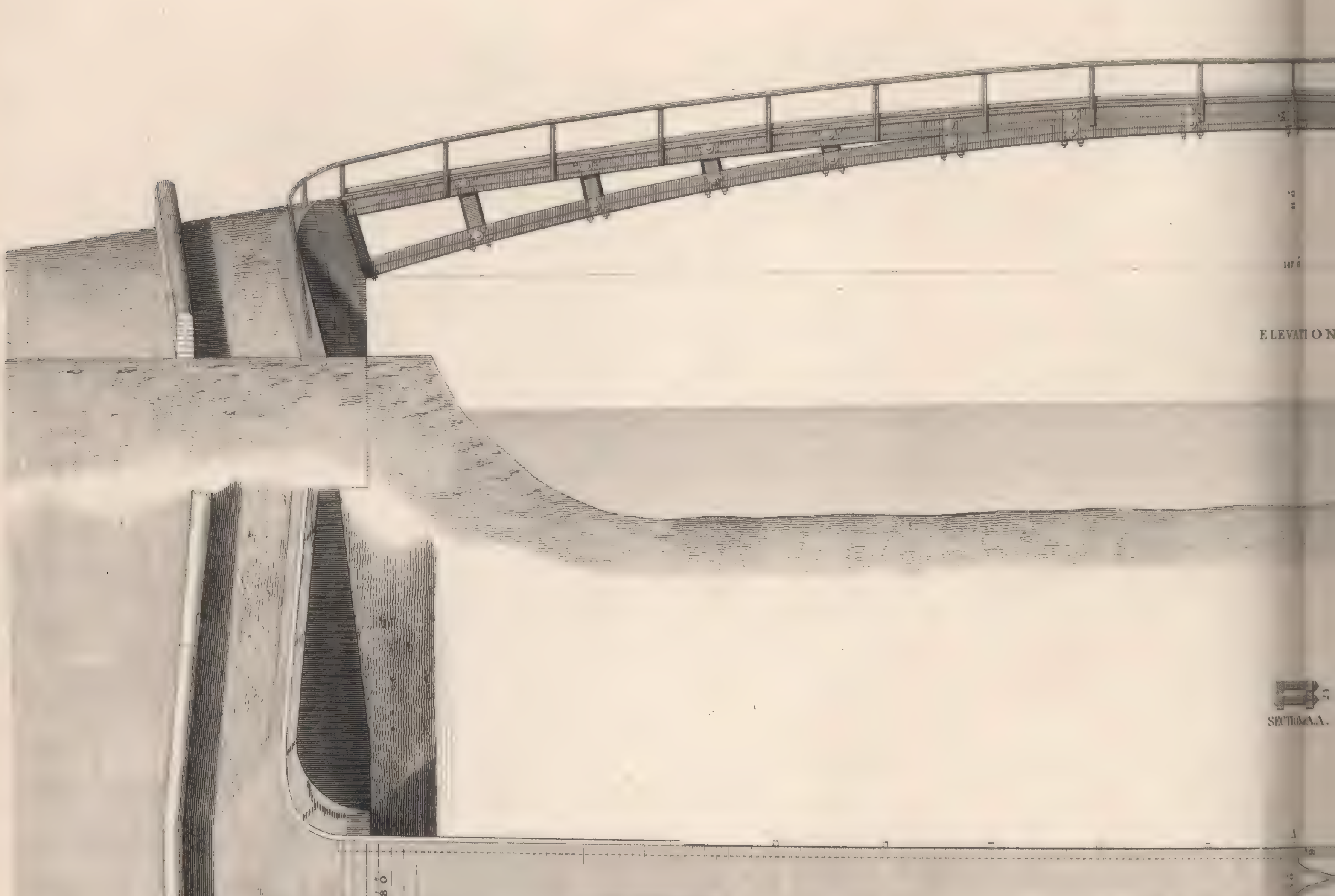
WOODEN BRIDGE OVER THE RIVER CA

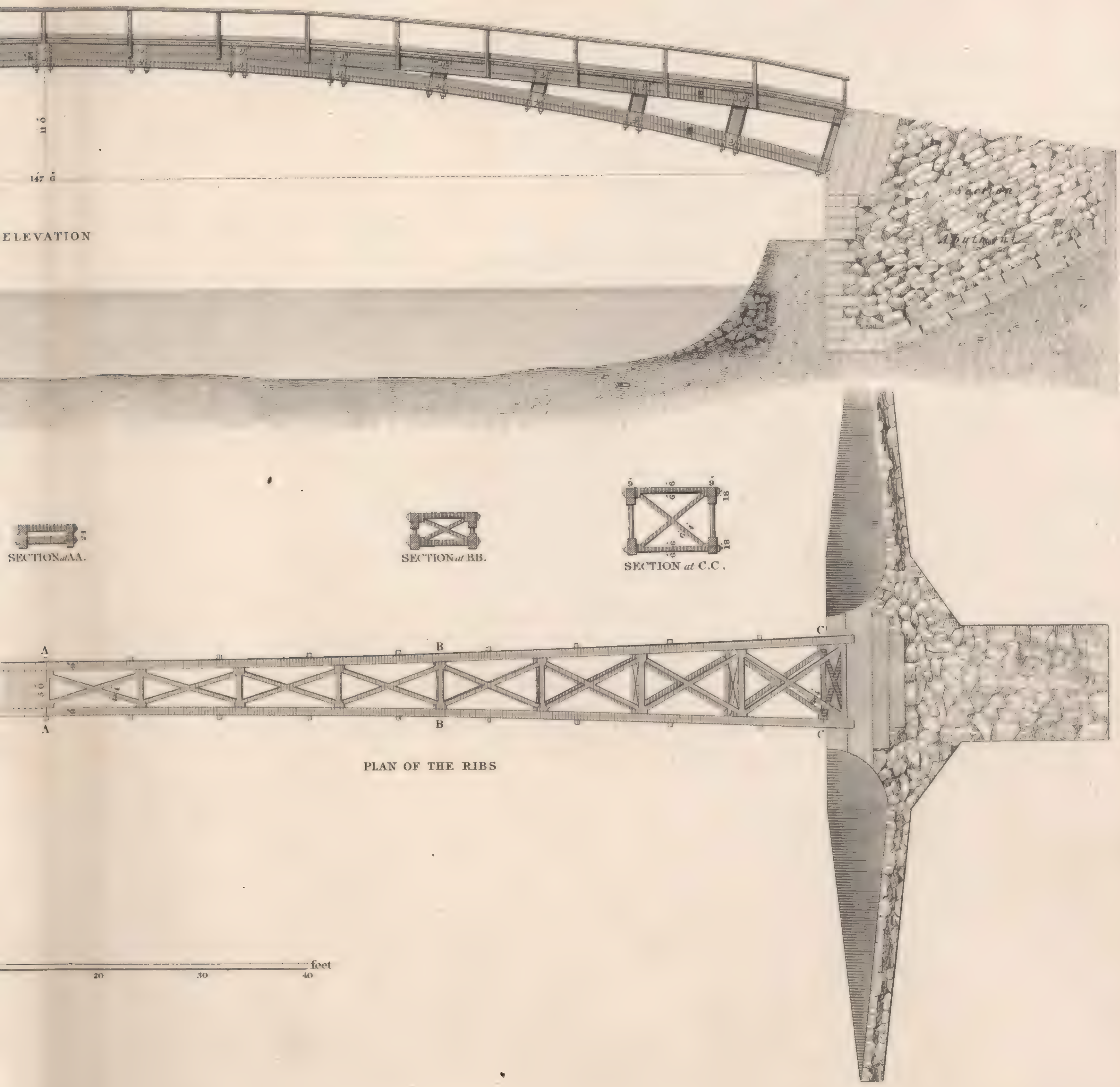
BY WILLIAM BULL,



W. Bull del.

VER CALDER AT MIRFIELD, YORKSHIRE,

BULL, CIVIL ENGINEER.



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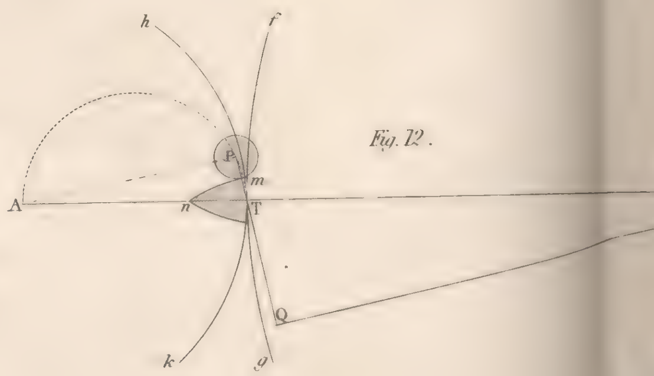
J.W.Lowry, sc.

Fig. 13.

Fig. 12.



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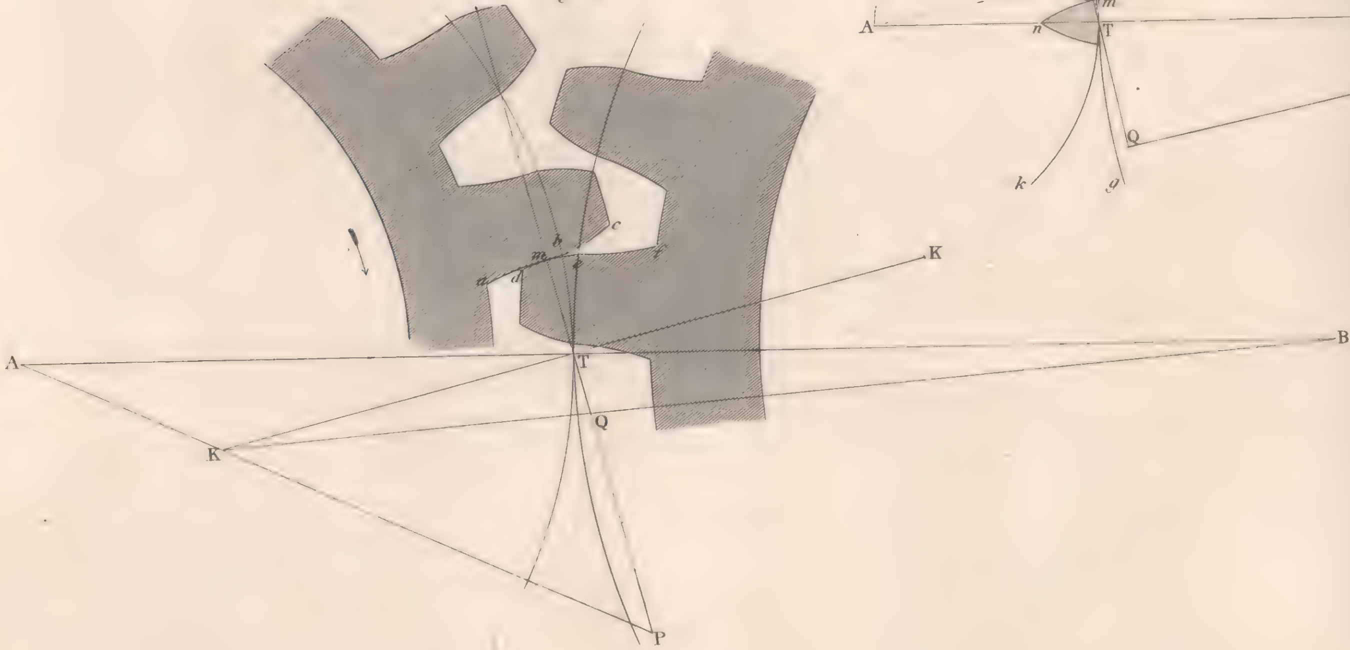
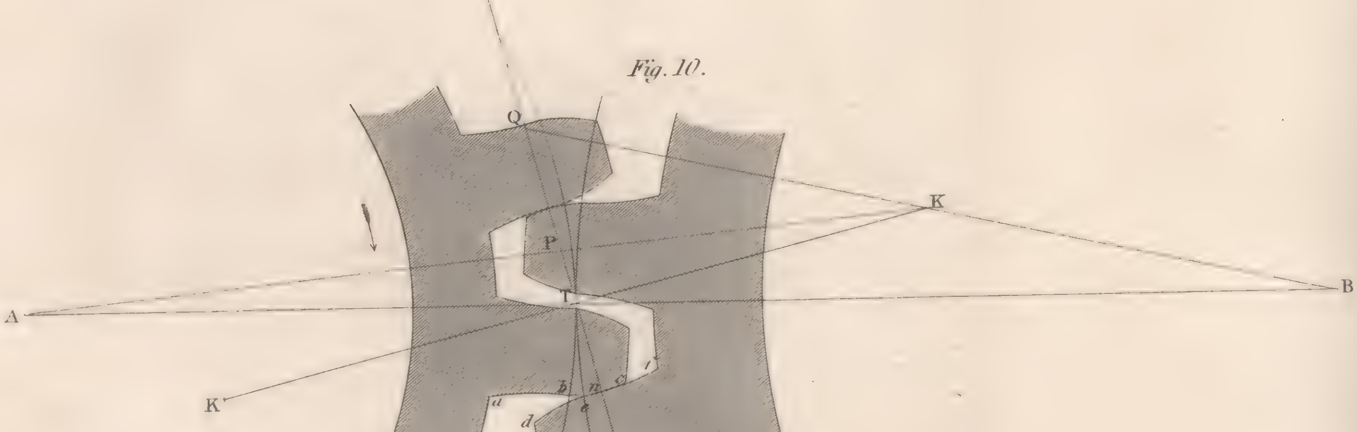


Fig. 10.

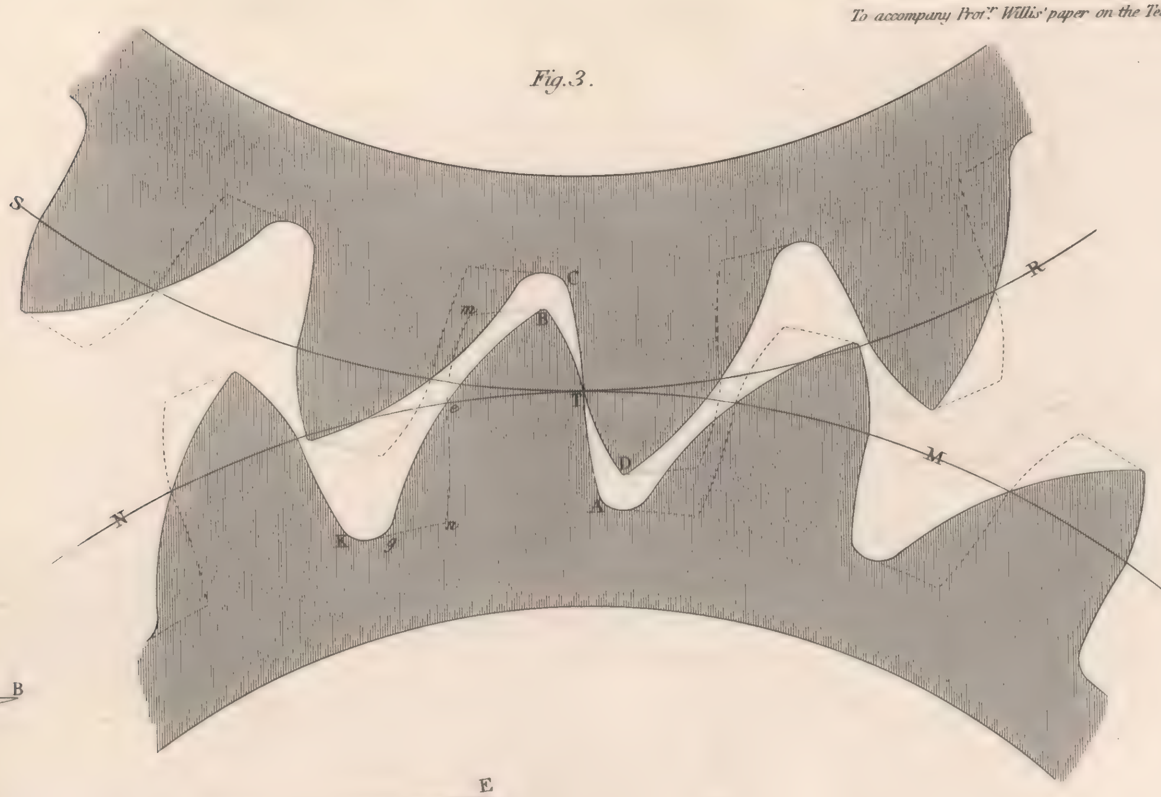


R. Willis del.

John Weale Architectural L

To accompany Prof.r Willis' paper on the Teeth of Wheels.

Fig. 3.



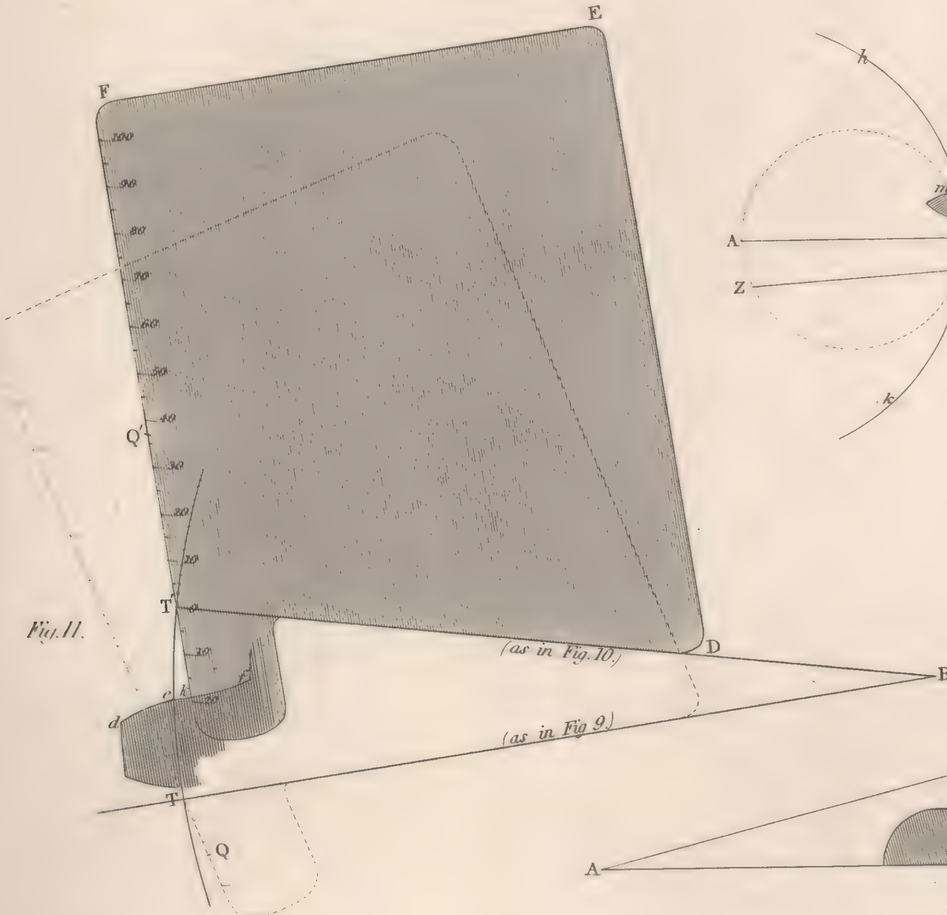


Fig. 11.

Fig. 14.

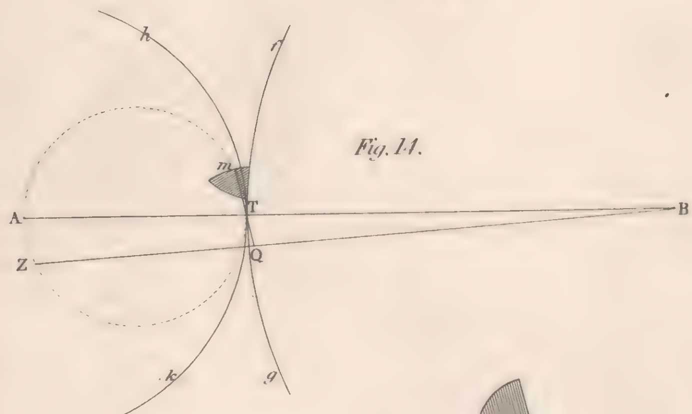
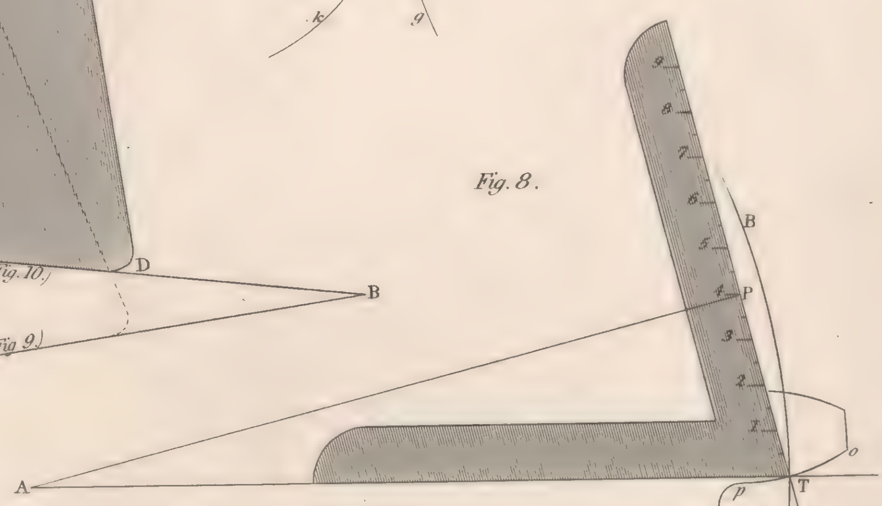
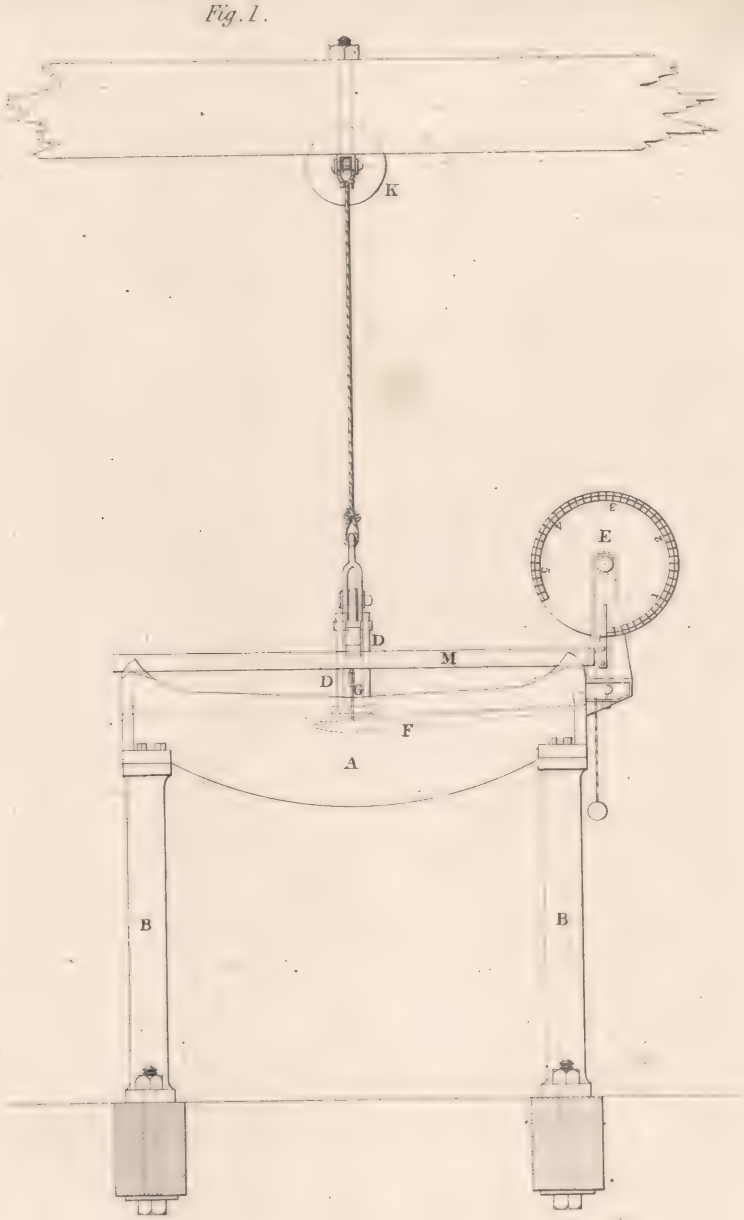


Fig. 8.



J.W. Lowry sc.

Fig. 1.



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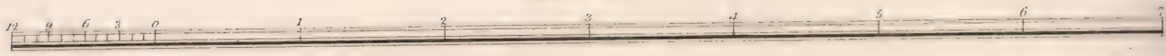

EXPERIMENTS ON CAST IRON.

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F. Bramah del.

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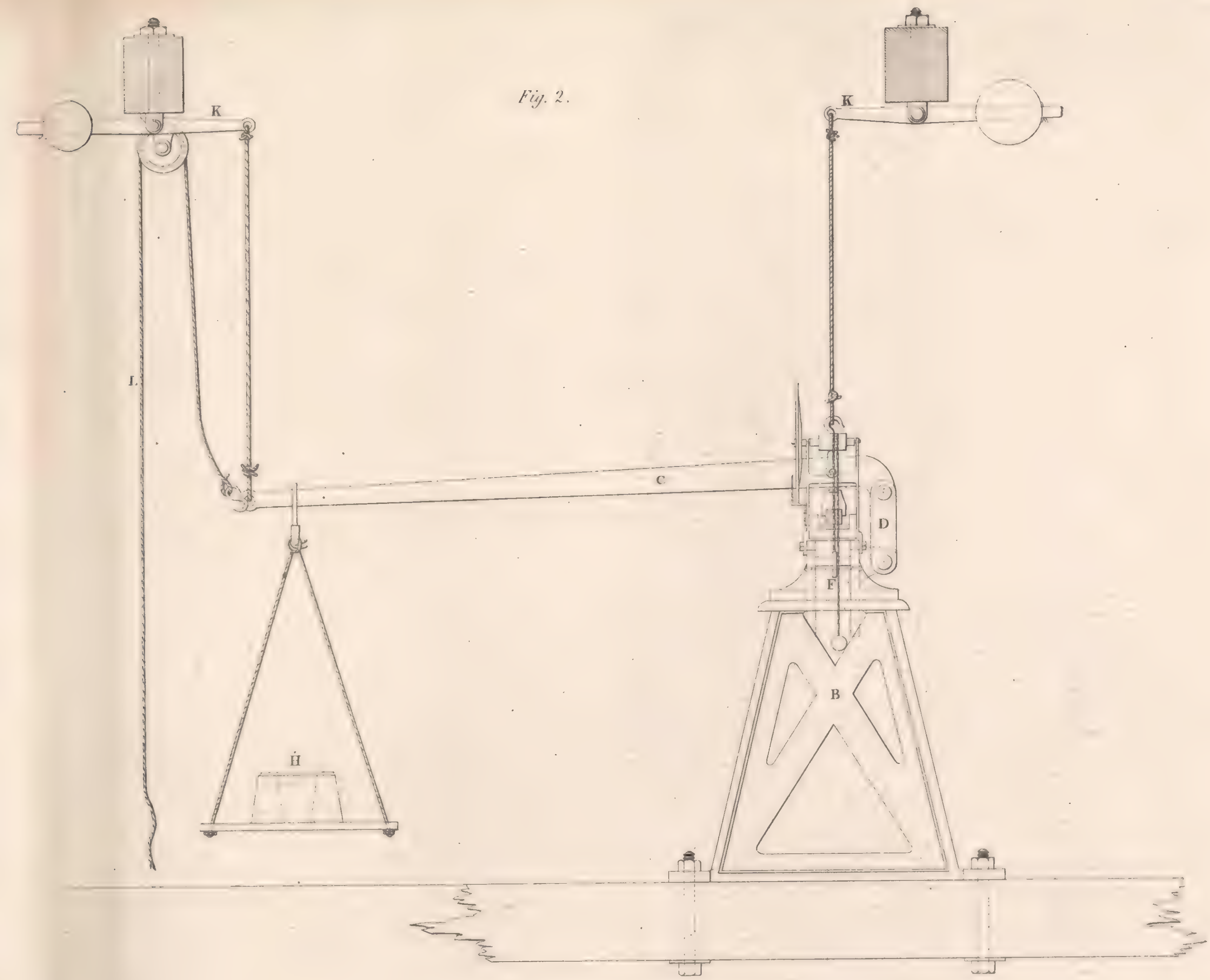
Fig. 2.



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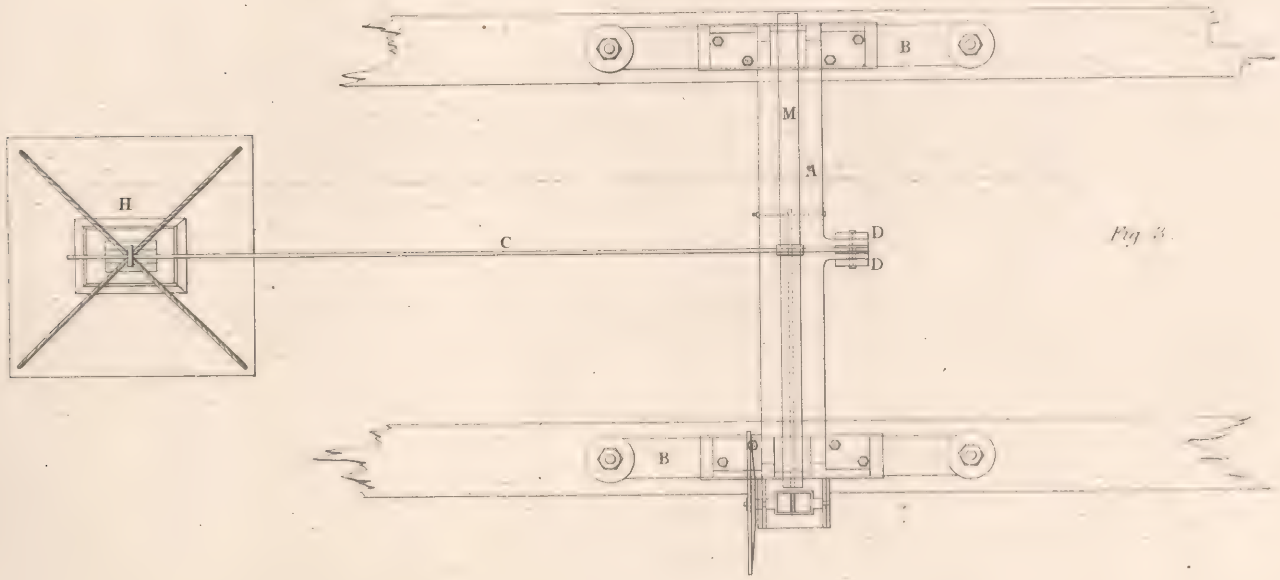

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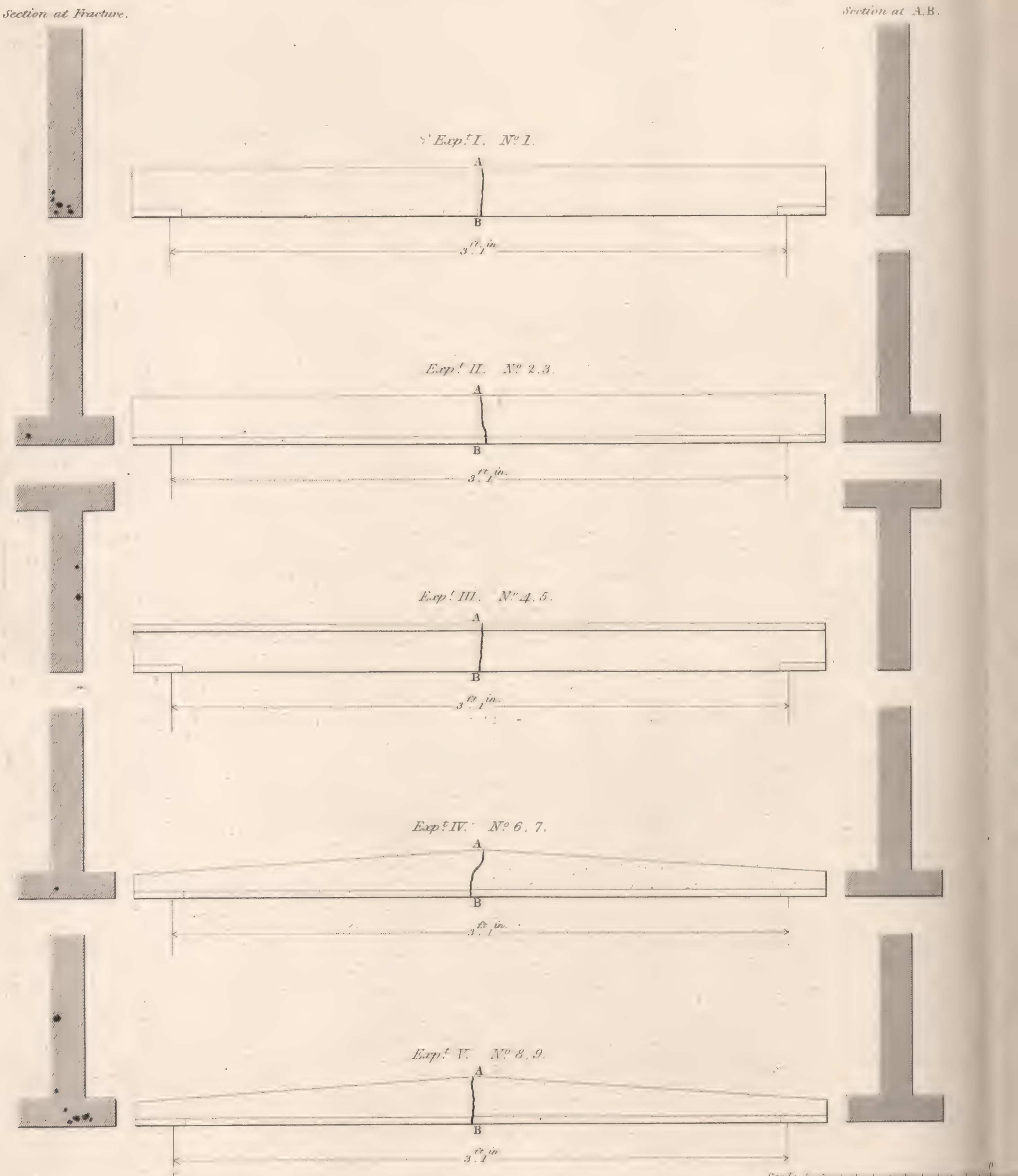

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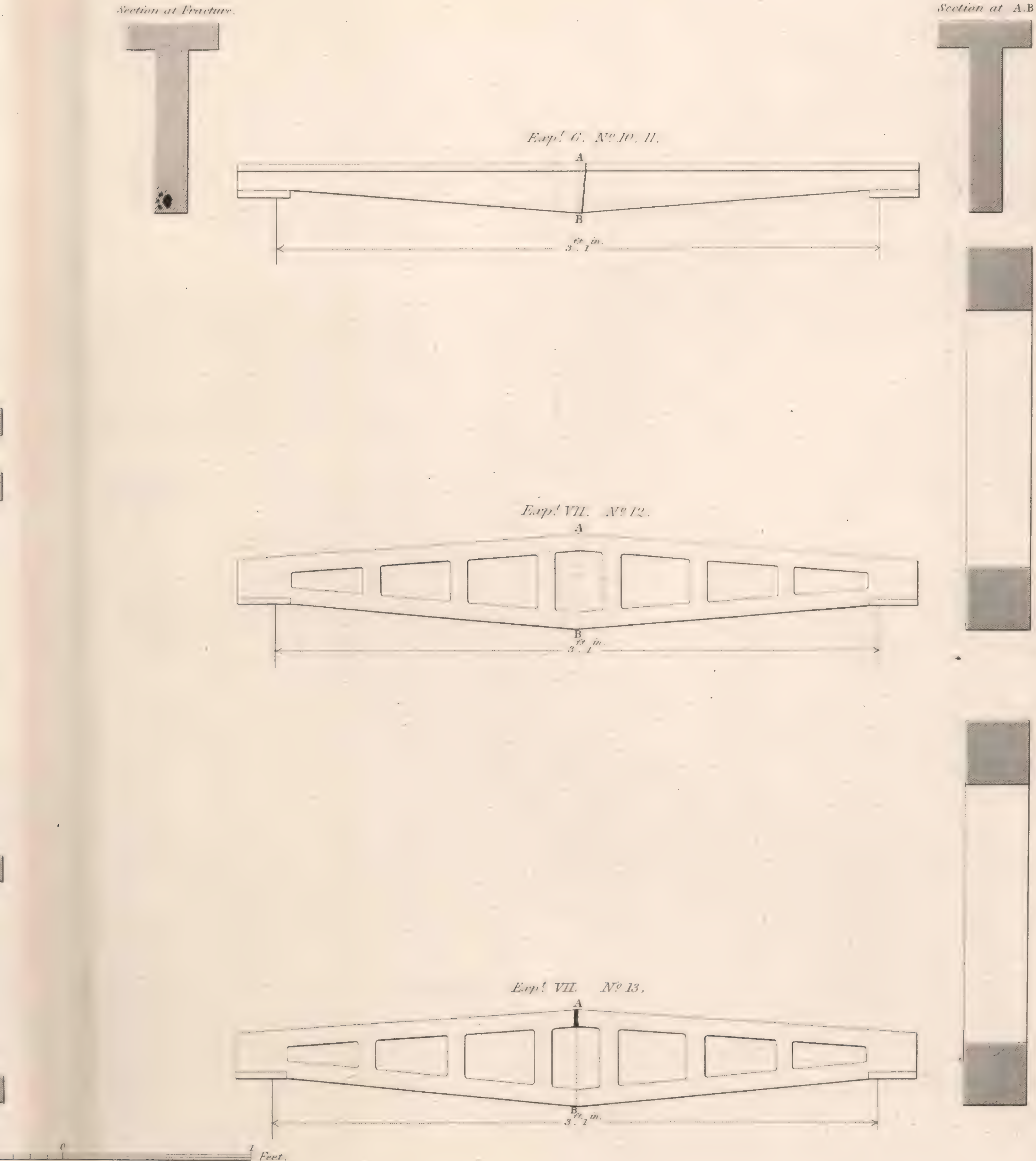
Plate X.



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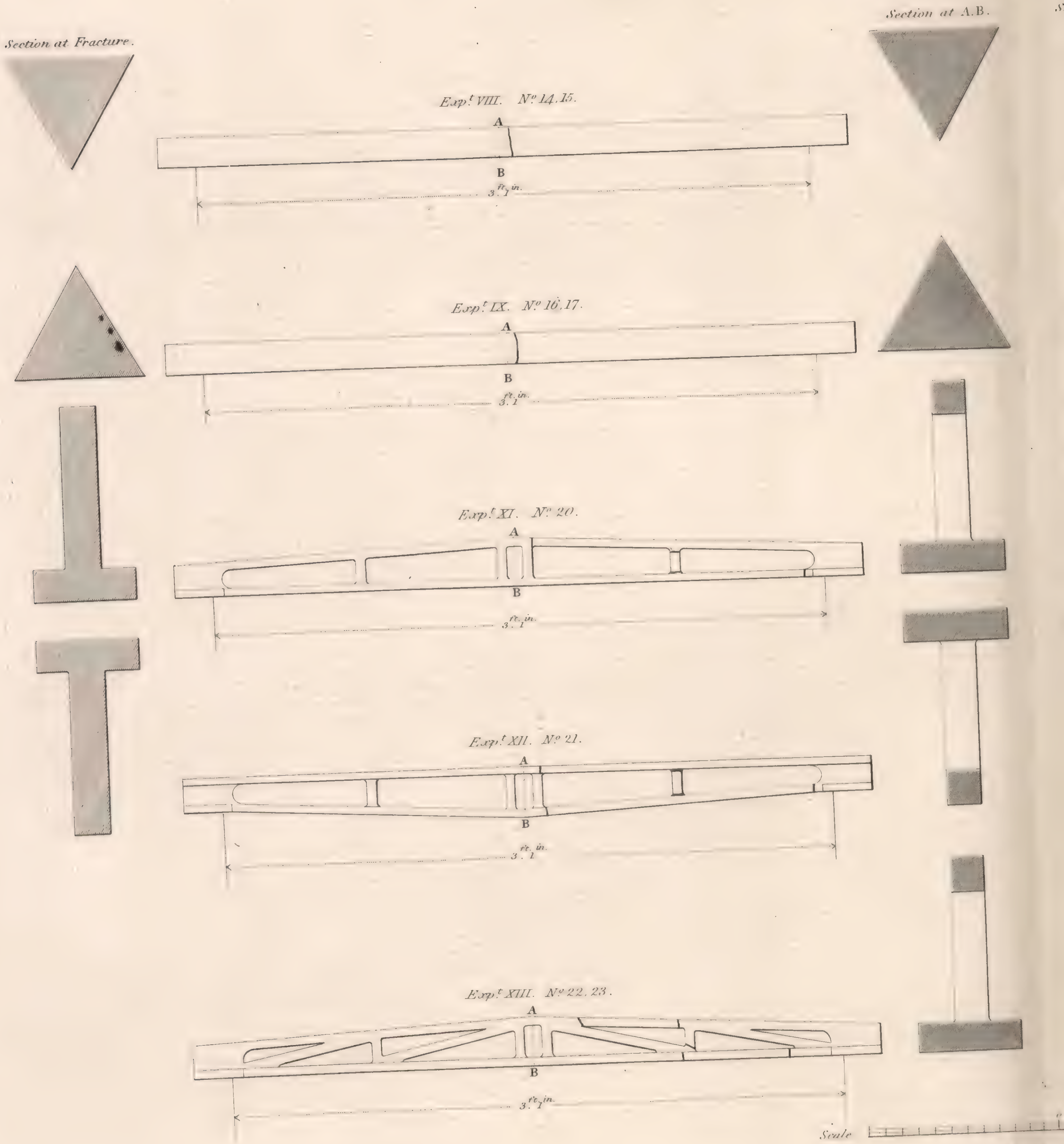

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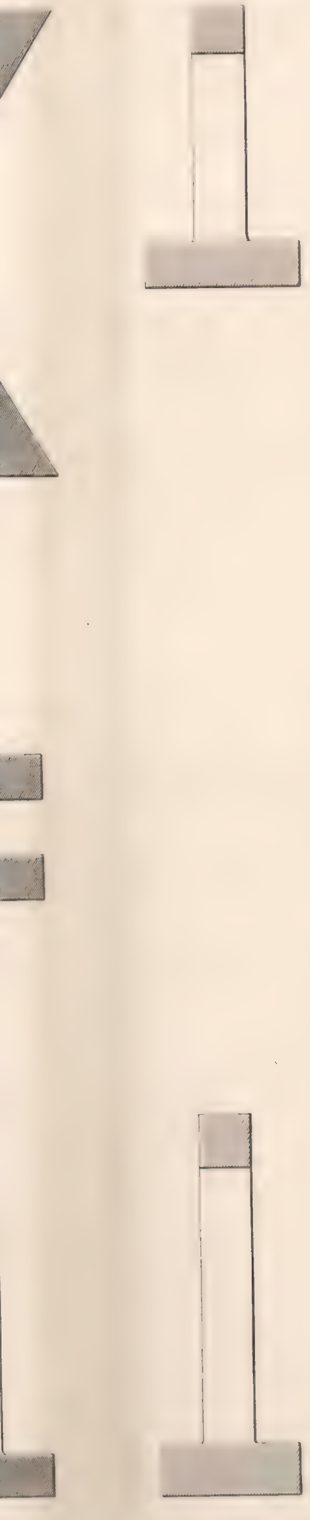
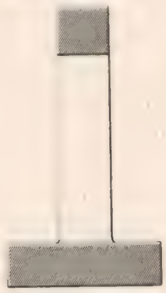
A.B.

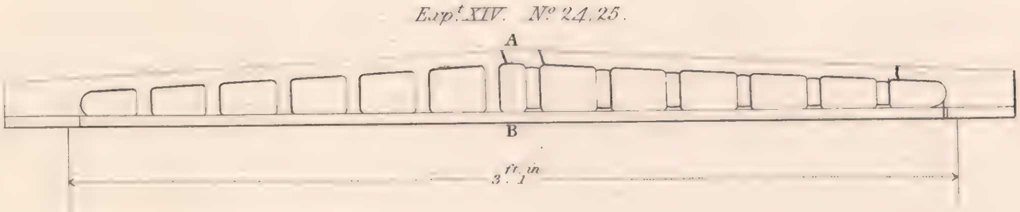
Section at Fracture.

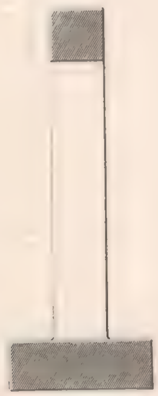


Section at A.B.



Expt. XIV. No. 24. 25.





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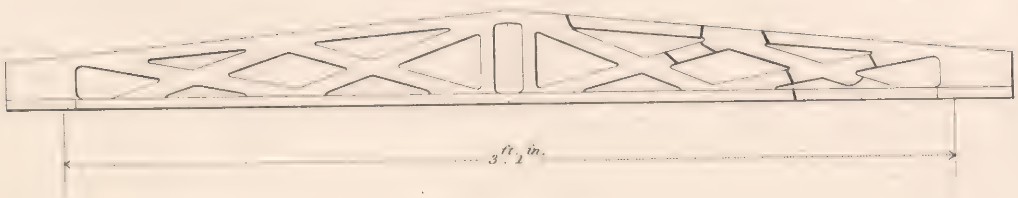
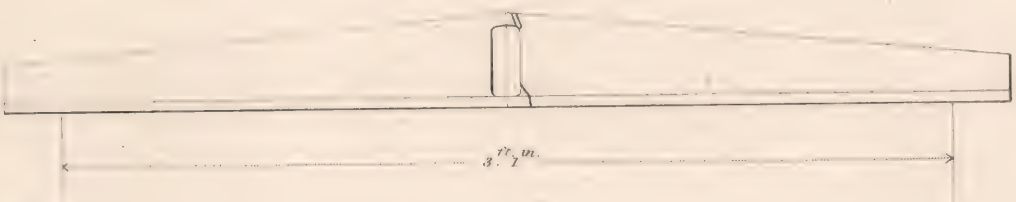


Expt. XVI. No. 28. 29.



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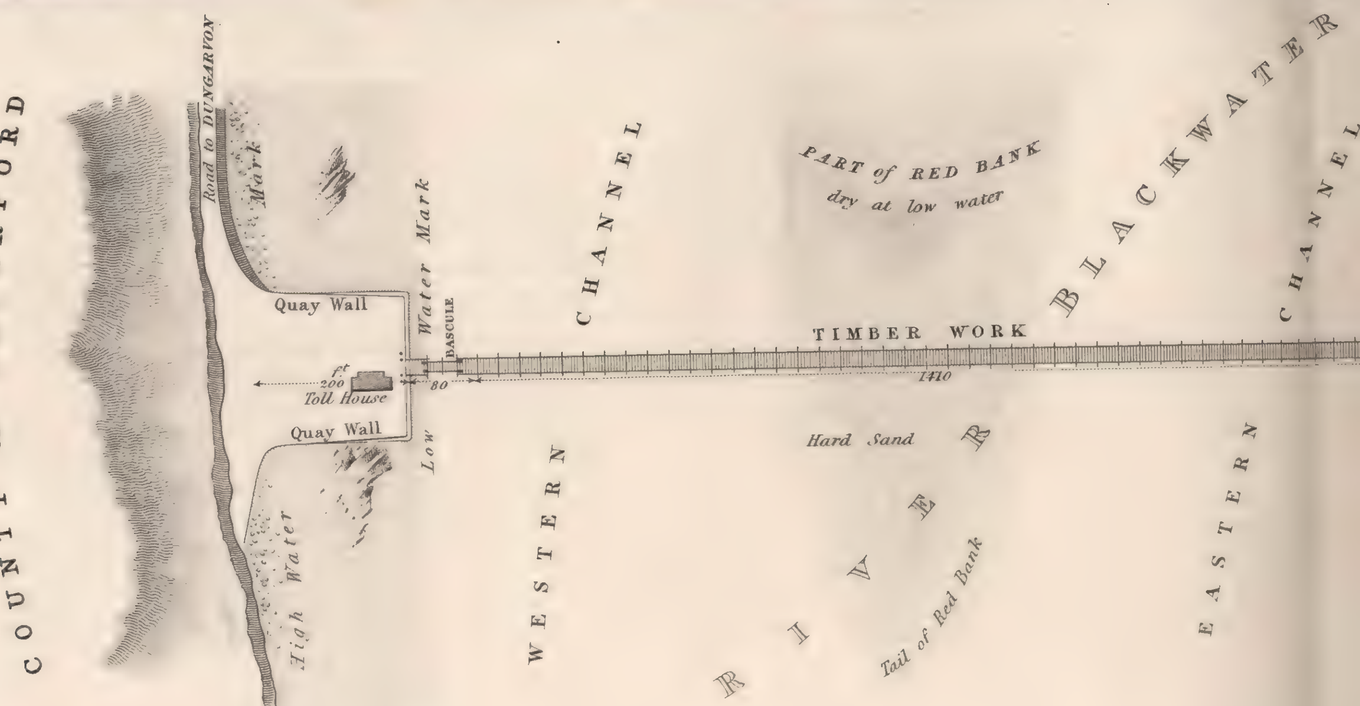

J.E.Jones del. C.E. Assoᵗ. I.C.E.

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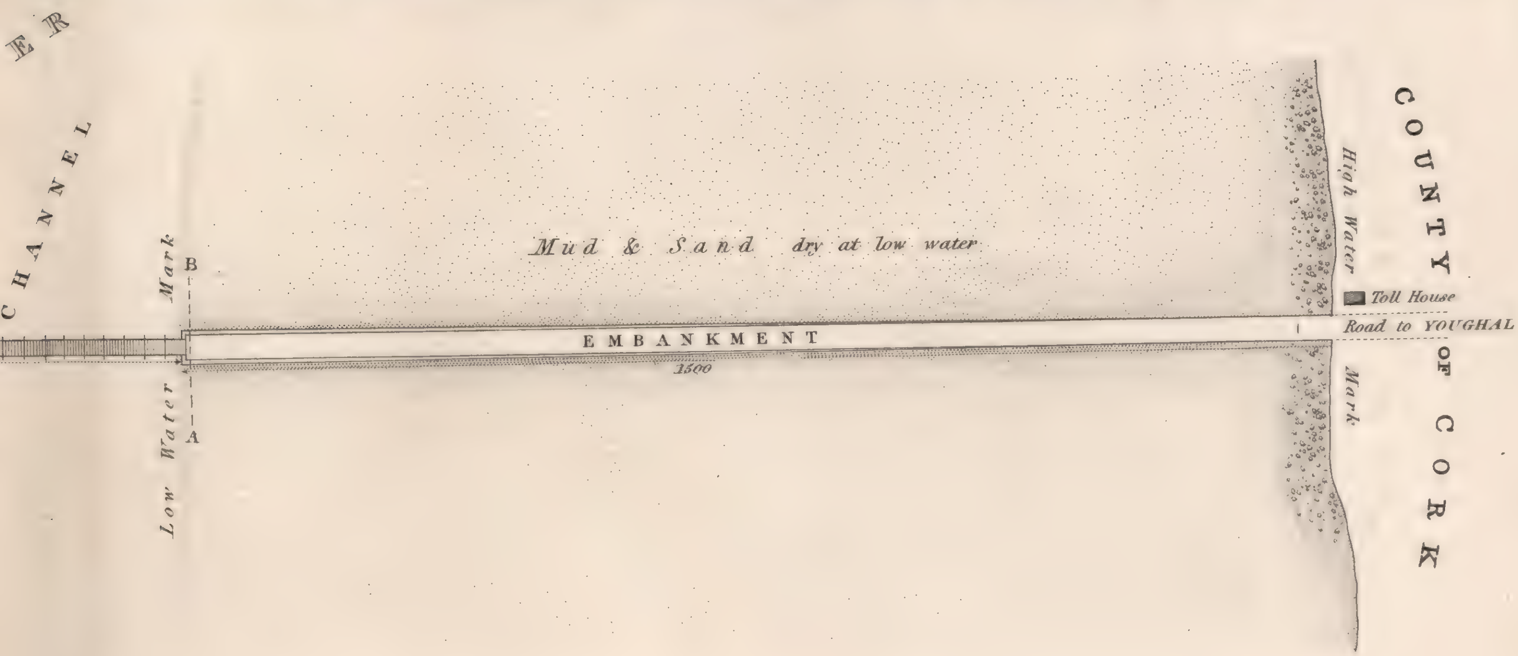

F. Mansell sc.

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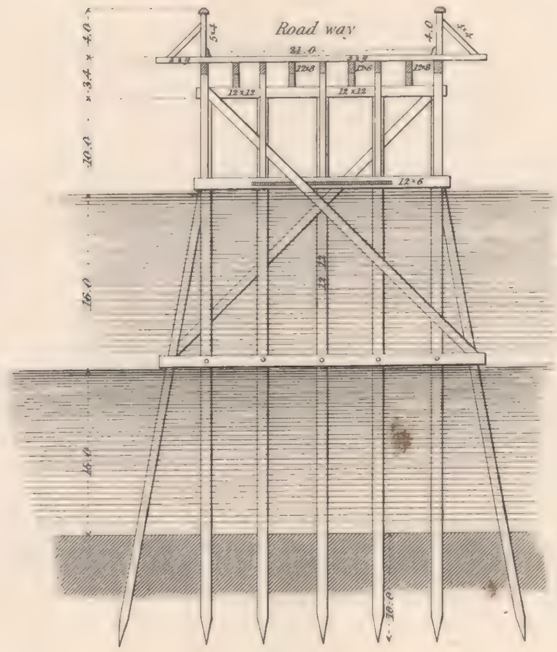
TRANSVERSE SECTION A.B.



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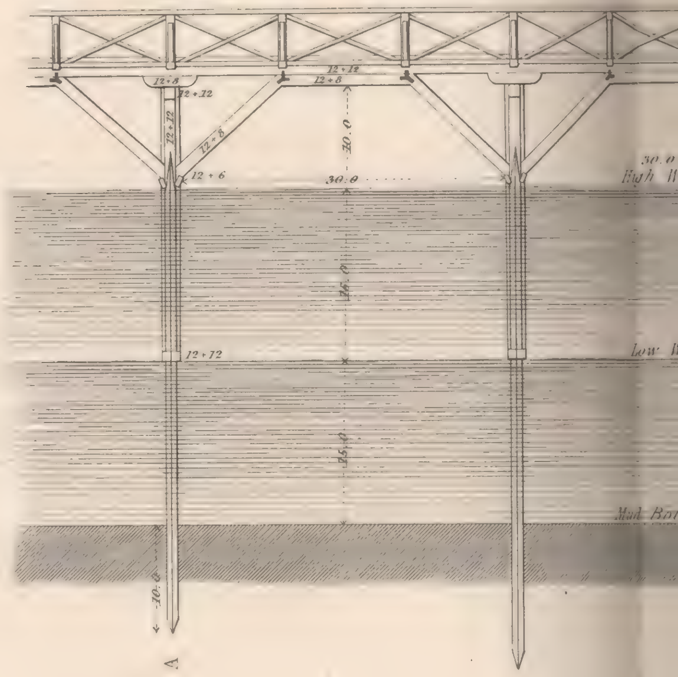
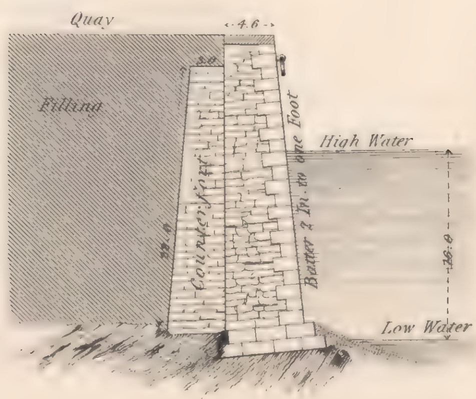


Scale 18 Feet

SECTION OF QUAY WALL



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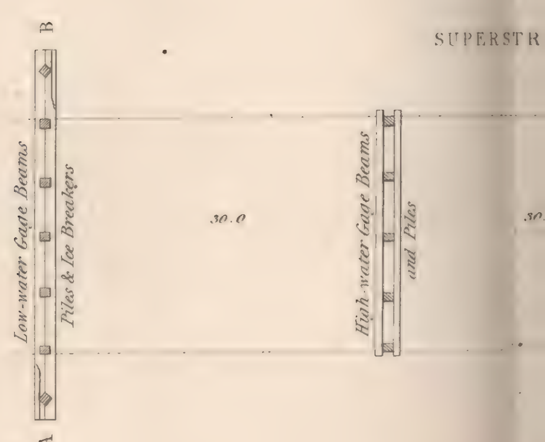

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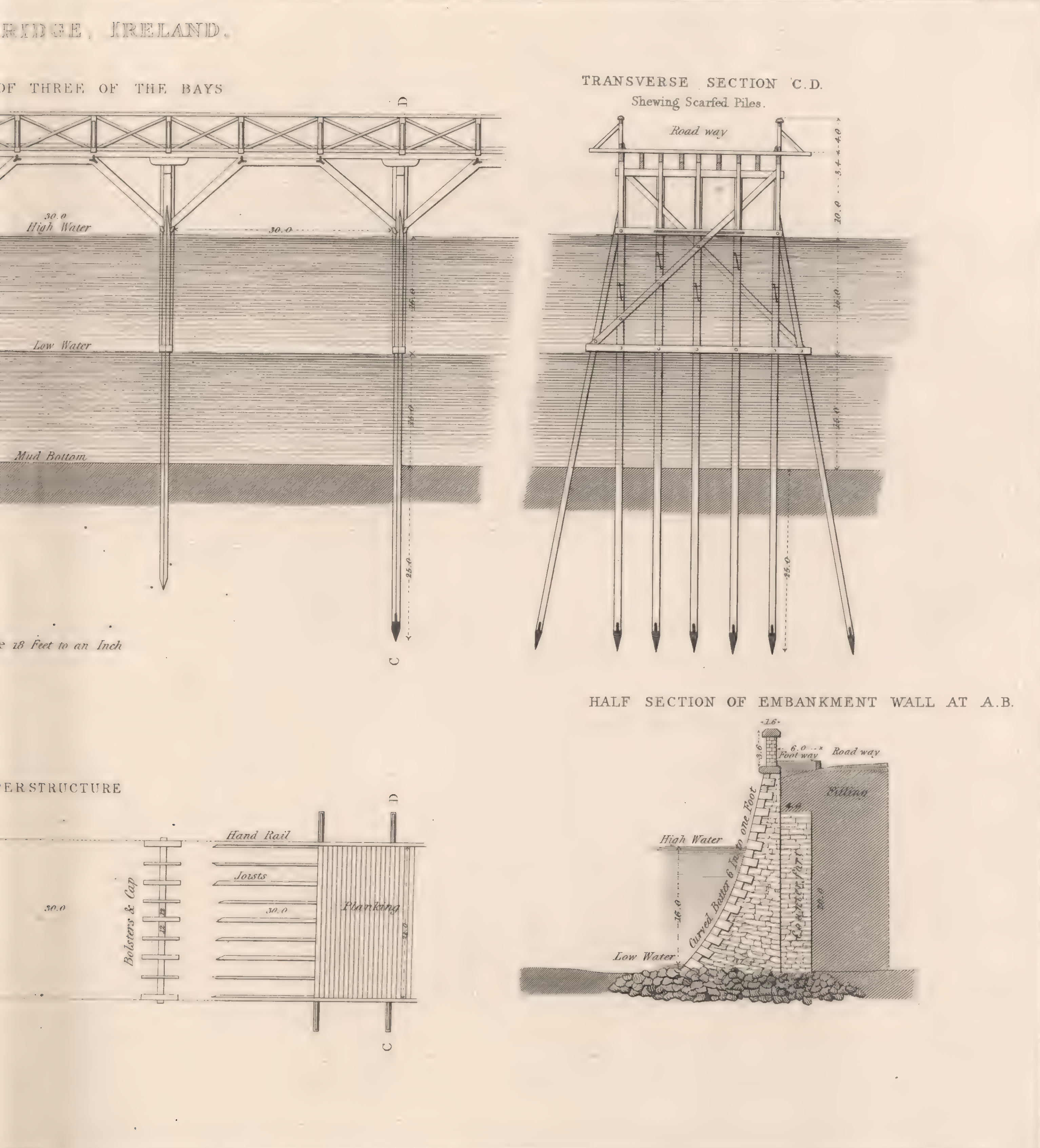


RIDGE, IRELAND.
OF THREE OF THE BAYS
D
30.0
High Water
30.0
26.0
Low Water
25.0
Mud Bottom
25.0
C
e 18 Feet to an Inch
TRANSVERSE SECTION C.D.
Shewing Scarfed Piles.
Road way
20.0
26.0
25.0
HALF SECTION OF EMBANKMENT WALL AT A.B.
1.6
3.6
6.0
Foot way
Road way
Filling
High Water
16.0
Curved Batter 6 In. to one Foot
Low Water
ERSTRUCTURE
D
Hand Rail
Joists
30.0
Bolsters & Cap
30.0
Planking
C

F. Mansell sc.

FIG. I.

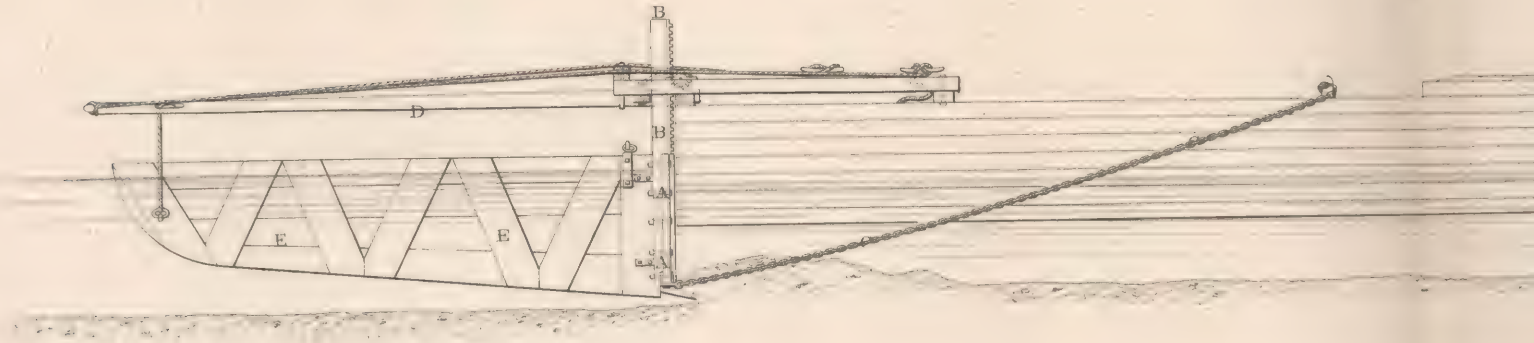
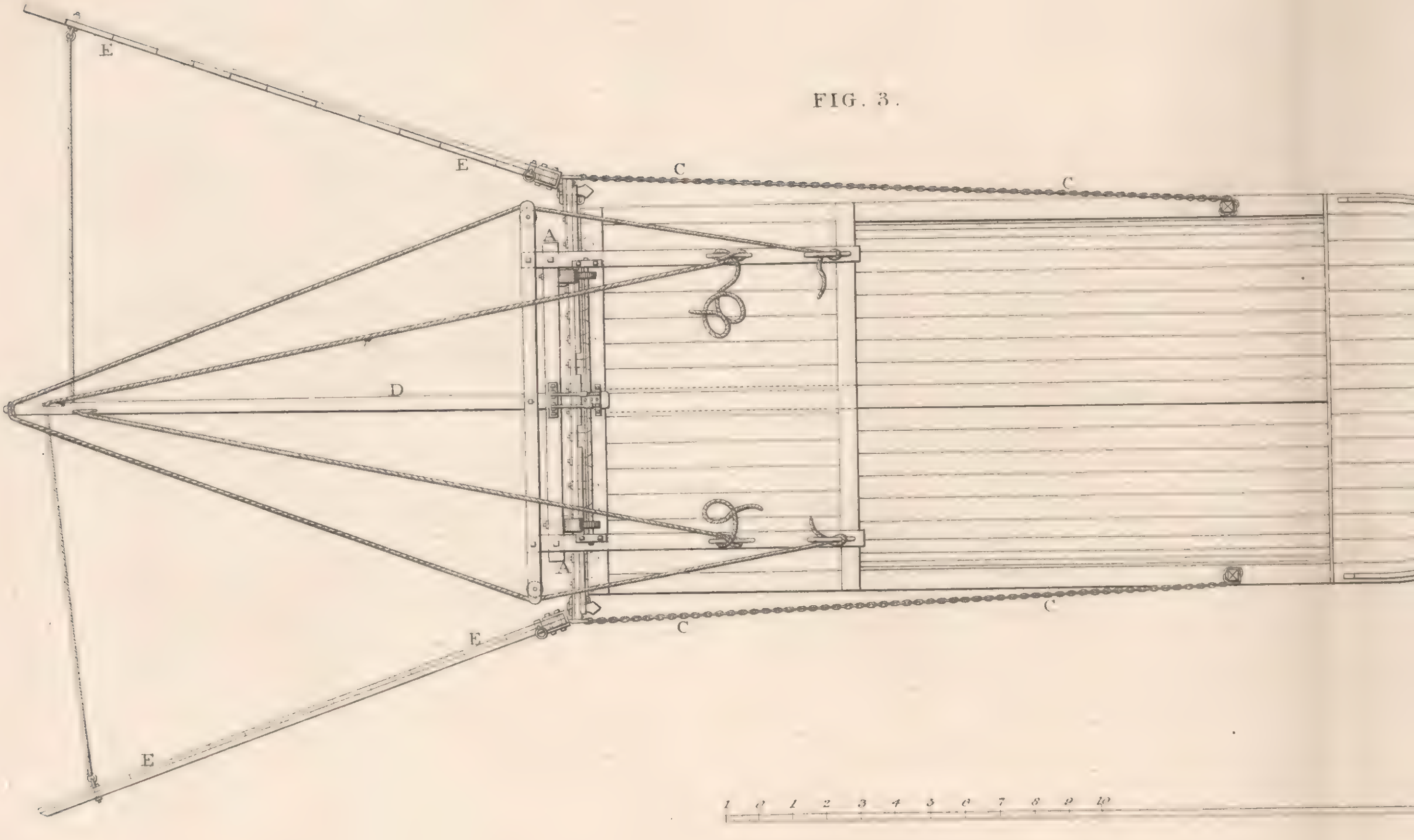


FIG. 3.



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W.B. Hayes del

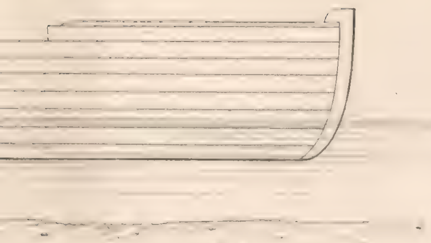
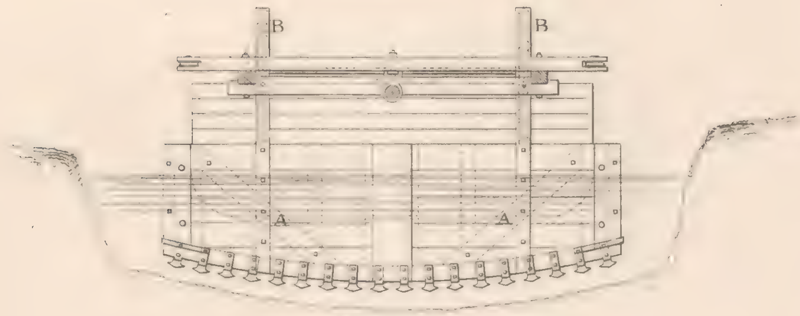
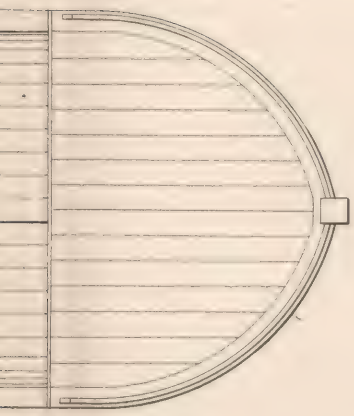


FIG. 2.





RIVER CLEANING MACHINE,

in use on

THE LITTLE STOUR, KENT.

W. B. Hays.

20 Feet

by G. A. Jermyn.

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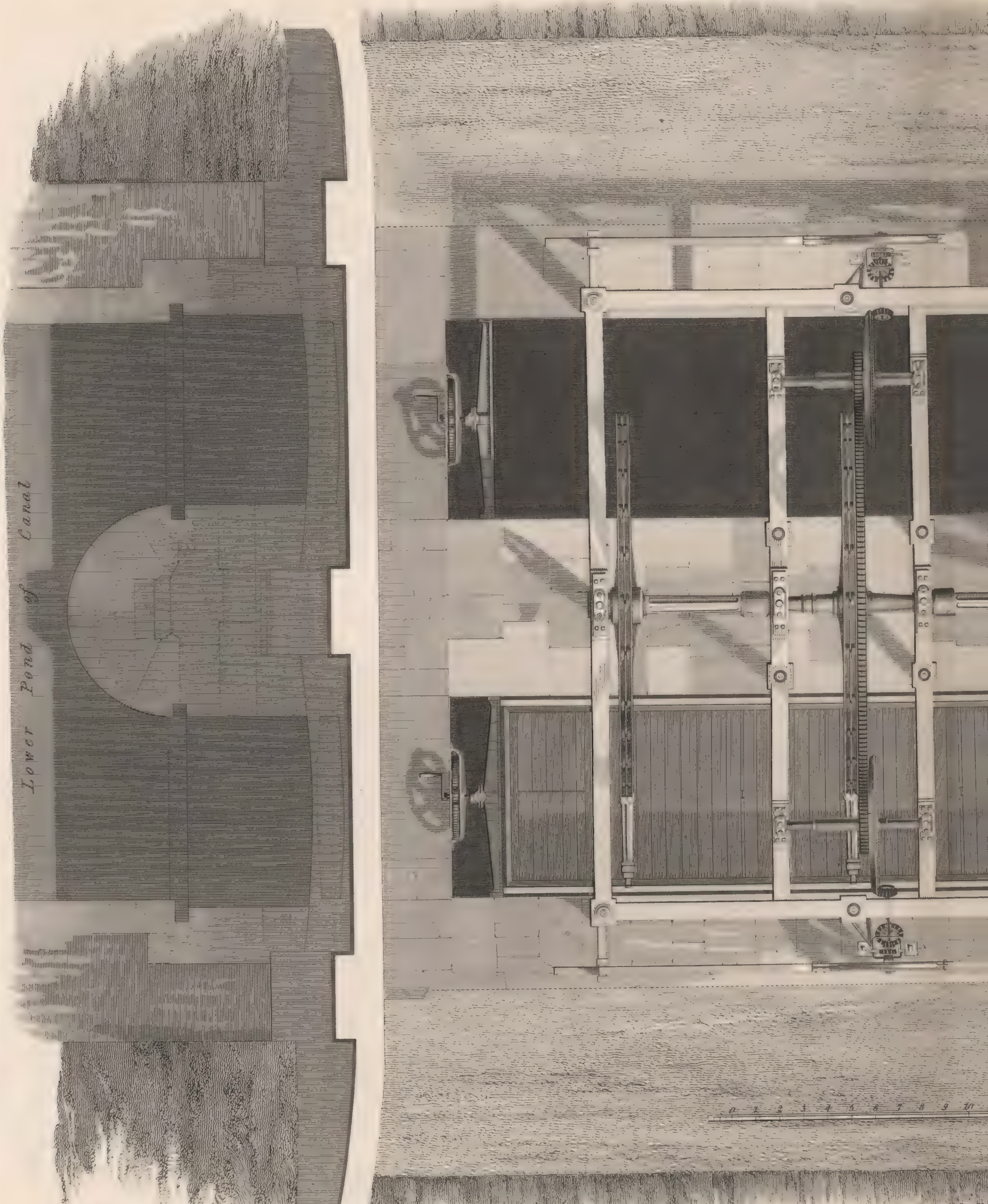
J. W. Lowry. Sculp.

GRAND WESTERN CANAL. P



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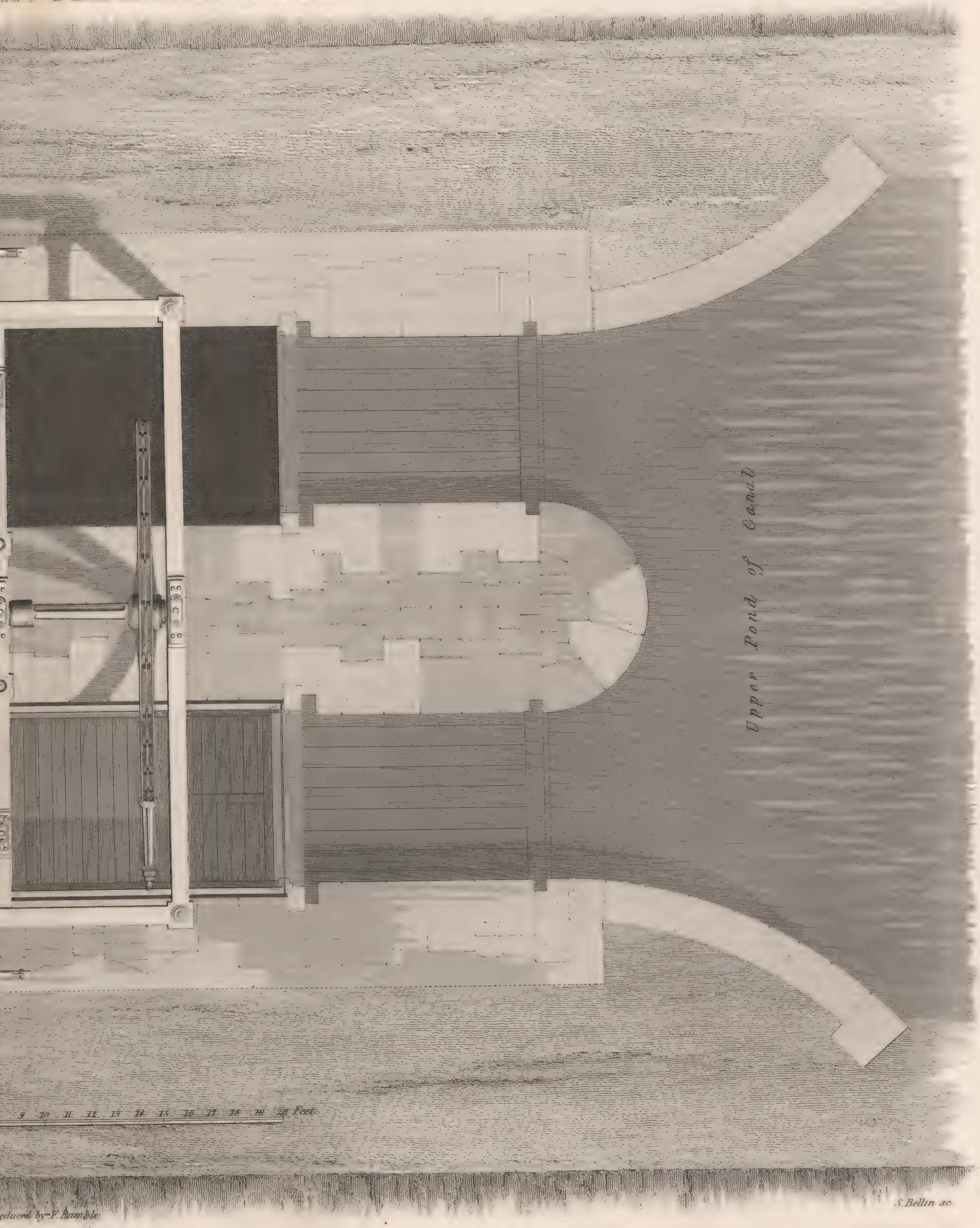

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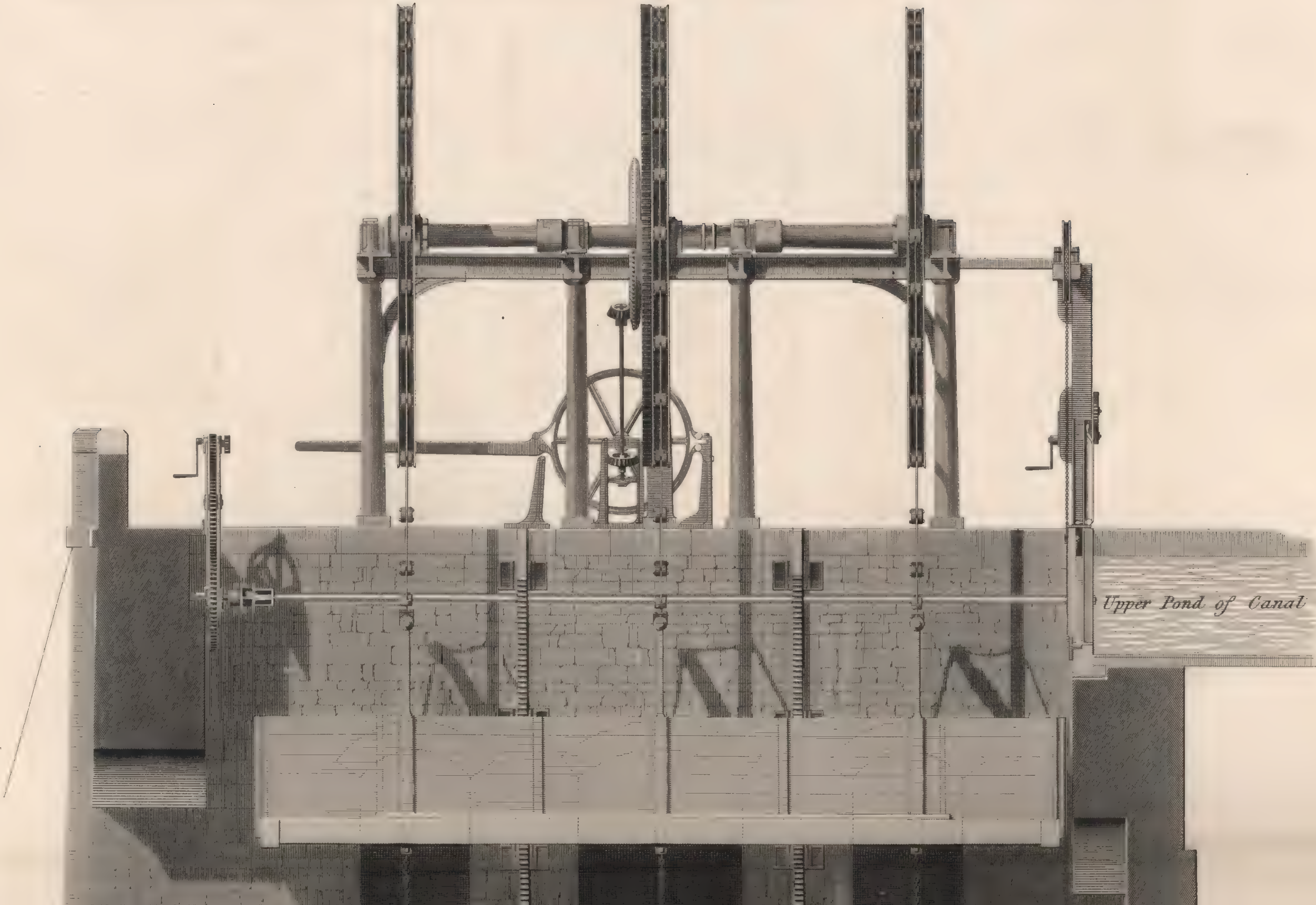
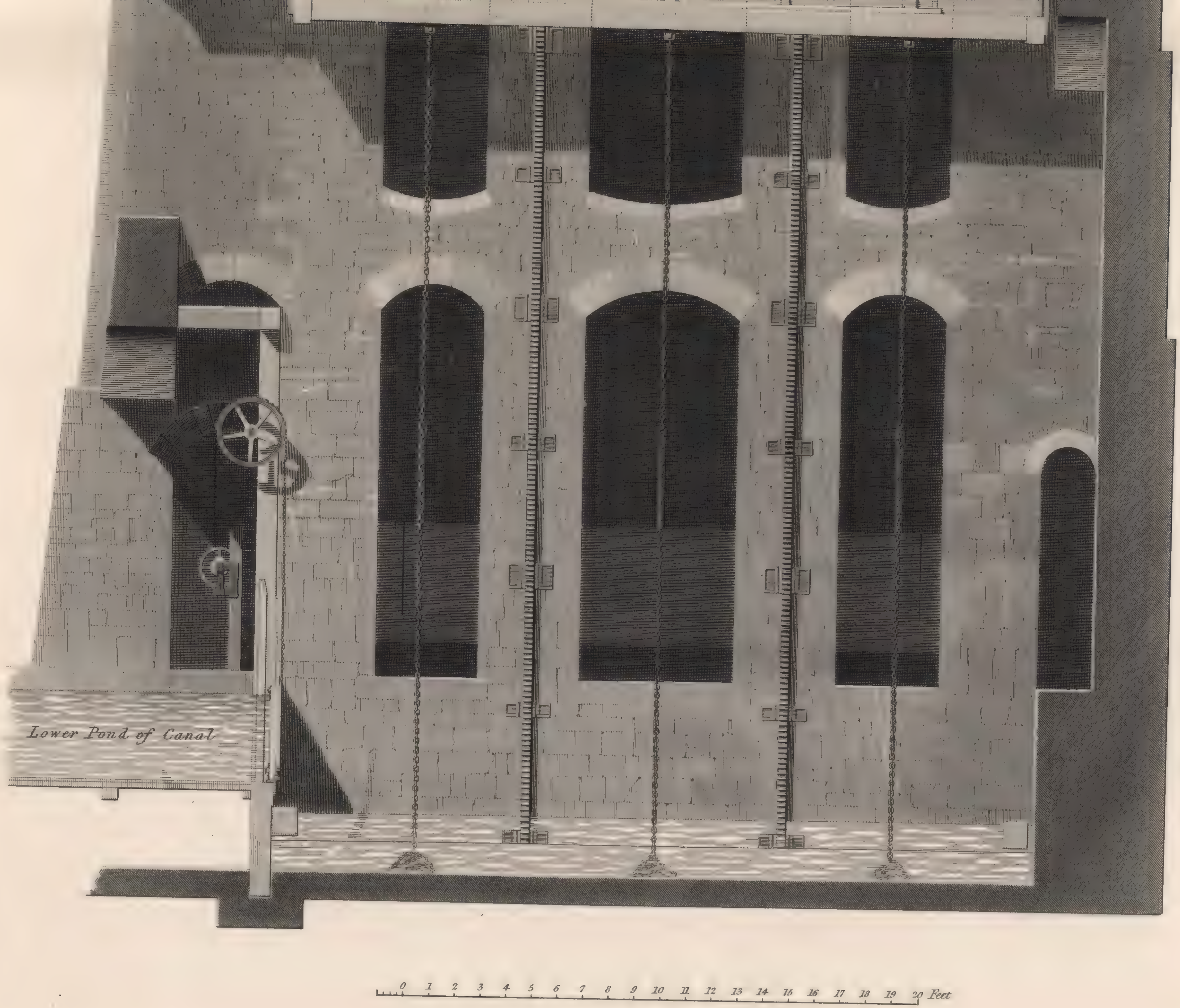
GRAND WESTERN CANAL, PERPENDICULAR LIFT.





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S. Bellin sc.

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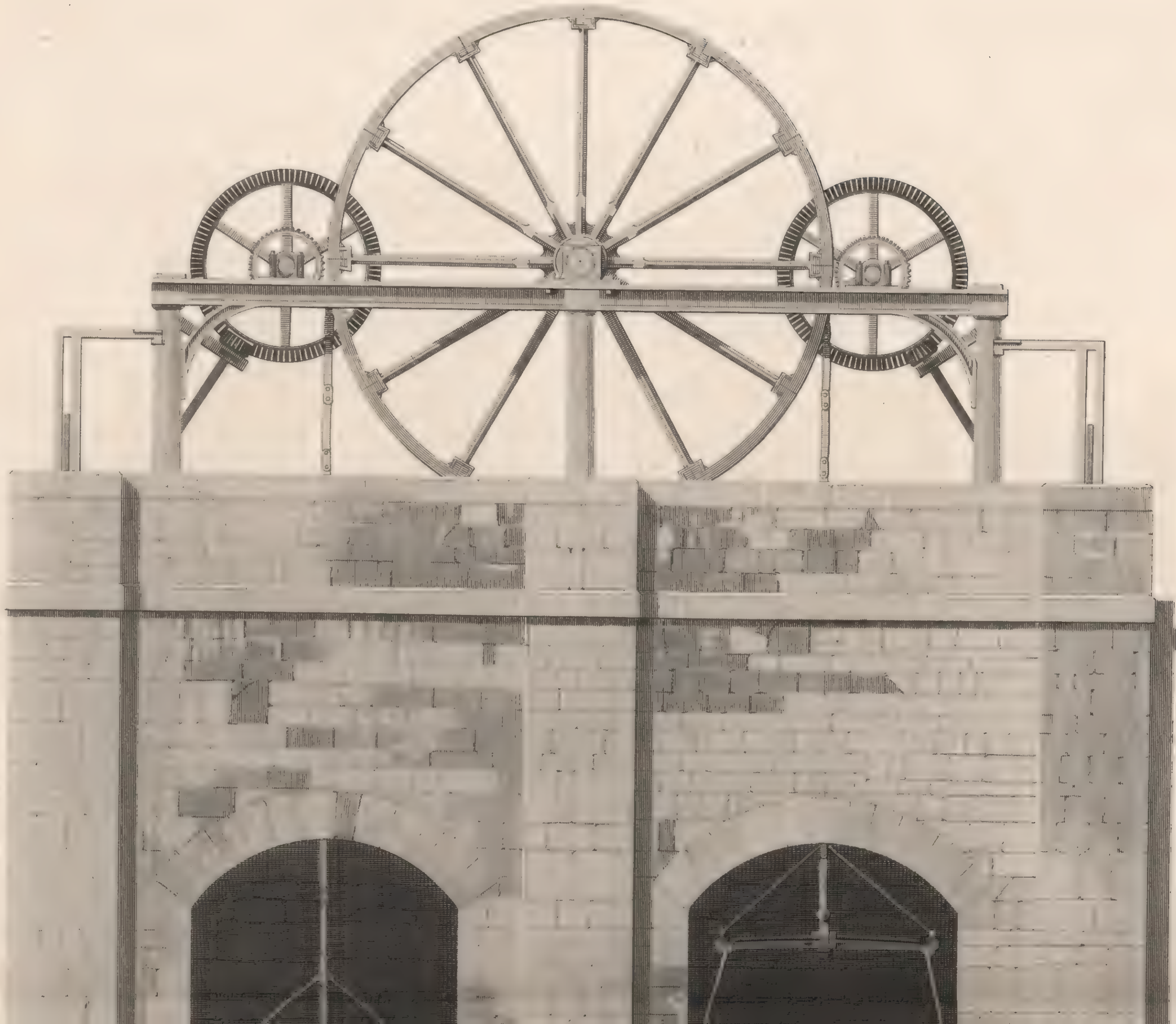
Plate XVIII

GRAND WESTERN CANAL, PERPENDICULAR LIFT.



TRANSVERSE SECTIONAL VIEW

J. Green del. | Reduced by F. Rumble | S. Bellin sc.

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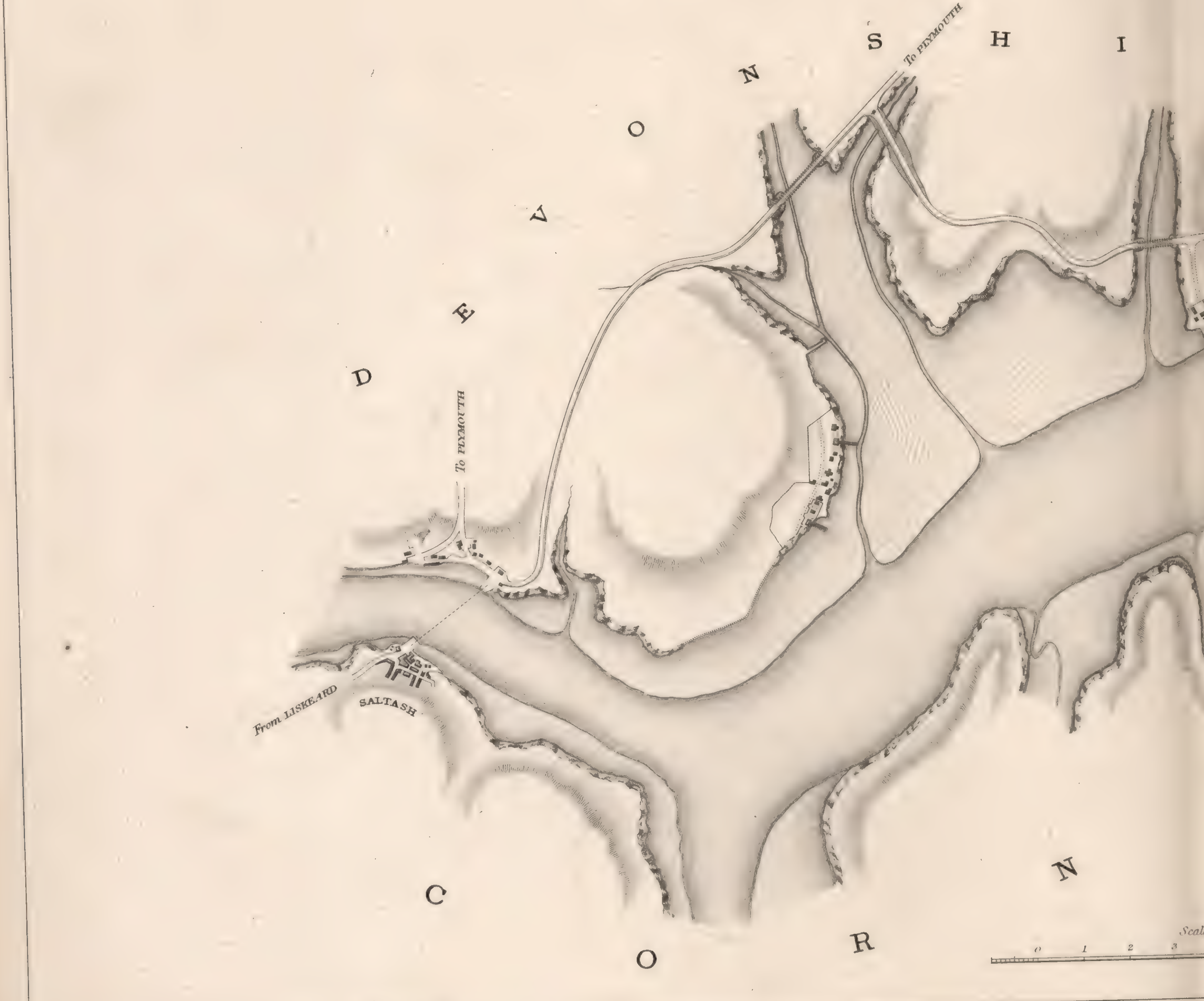
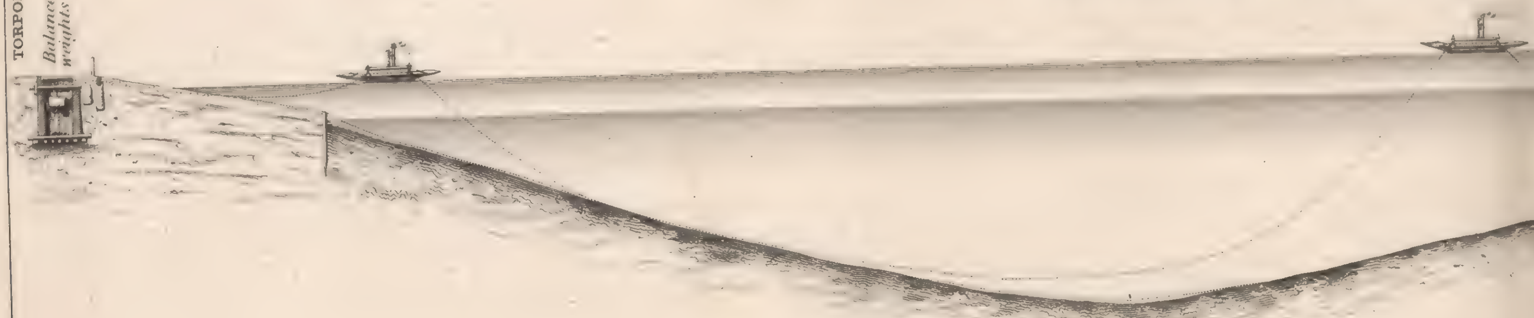
PLAN OF THE

SHOWING THE SITE OF THE TO



SECTION OF THE RIVER AT T

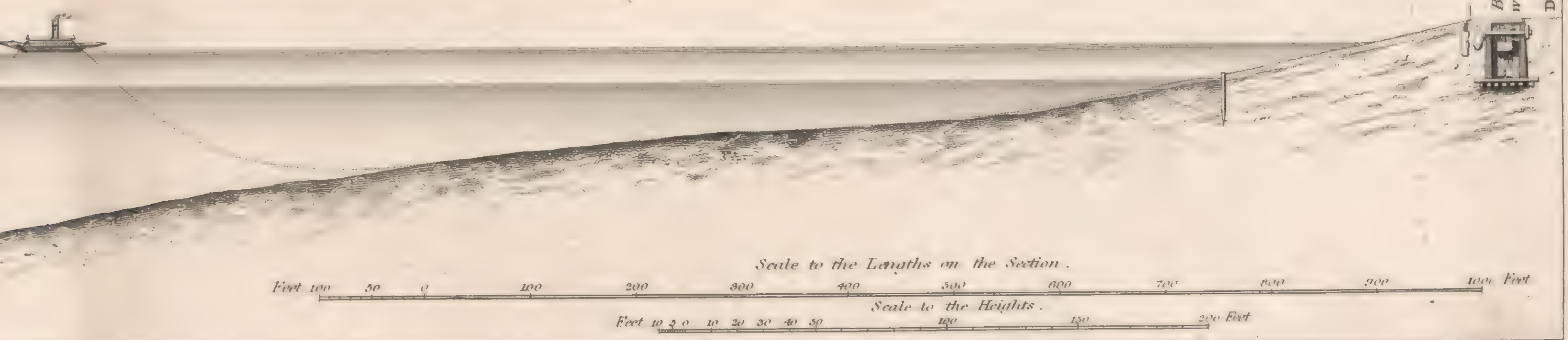


G. C. Dobson del.

John Weale, Architectural L

F THE HAMOAZE,
THE TORPOINT FLOATING BRIDGE.

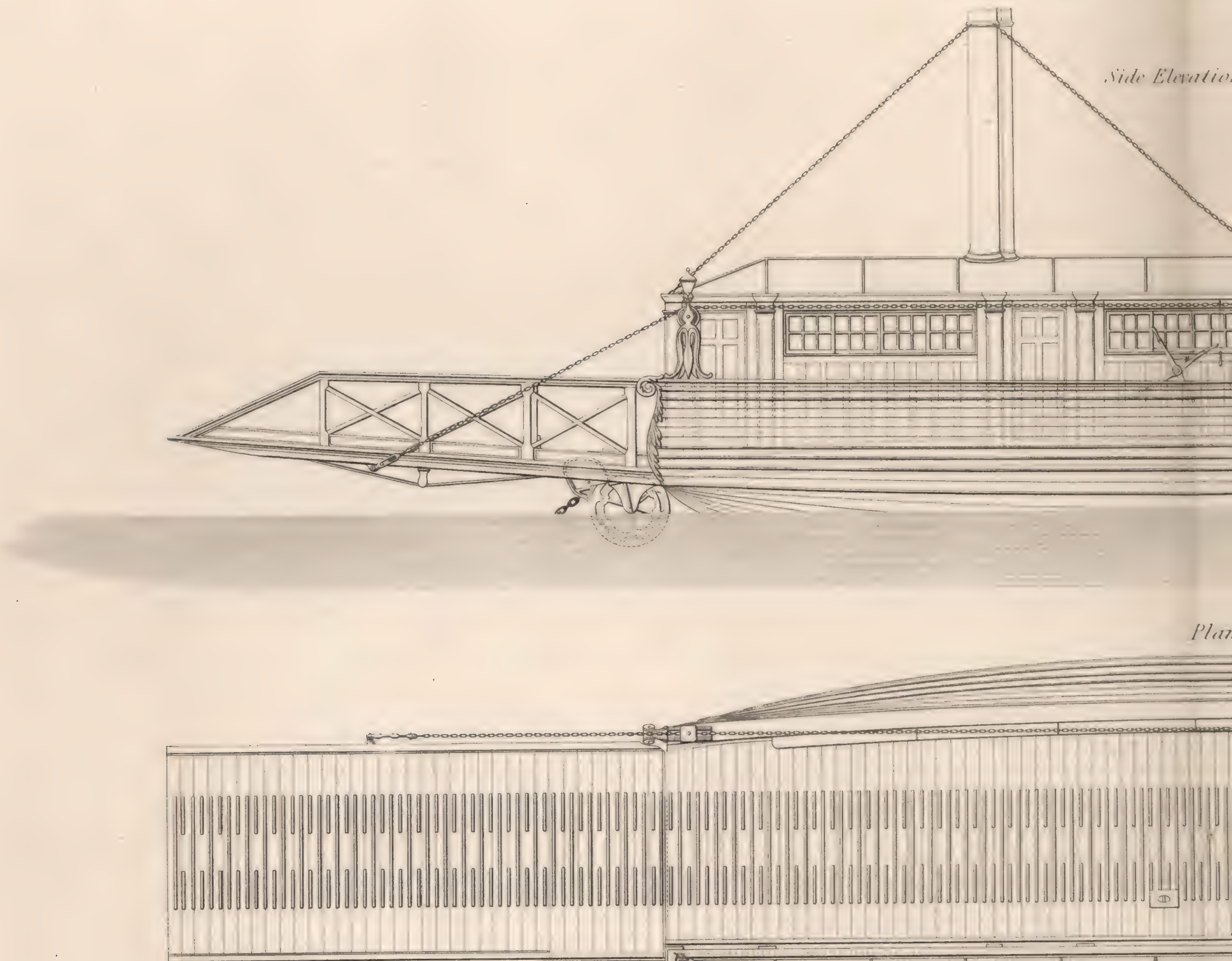
ER AT THE SITE OF THE BRIDGE.



R.R. Davies sculp.

rchitectural Library, 59, High Holborn.

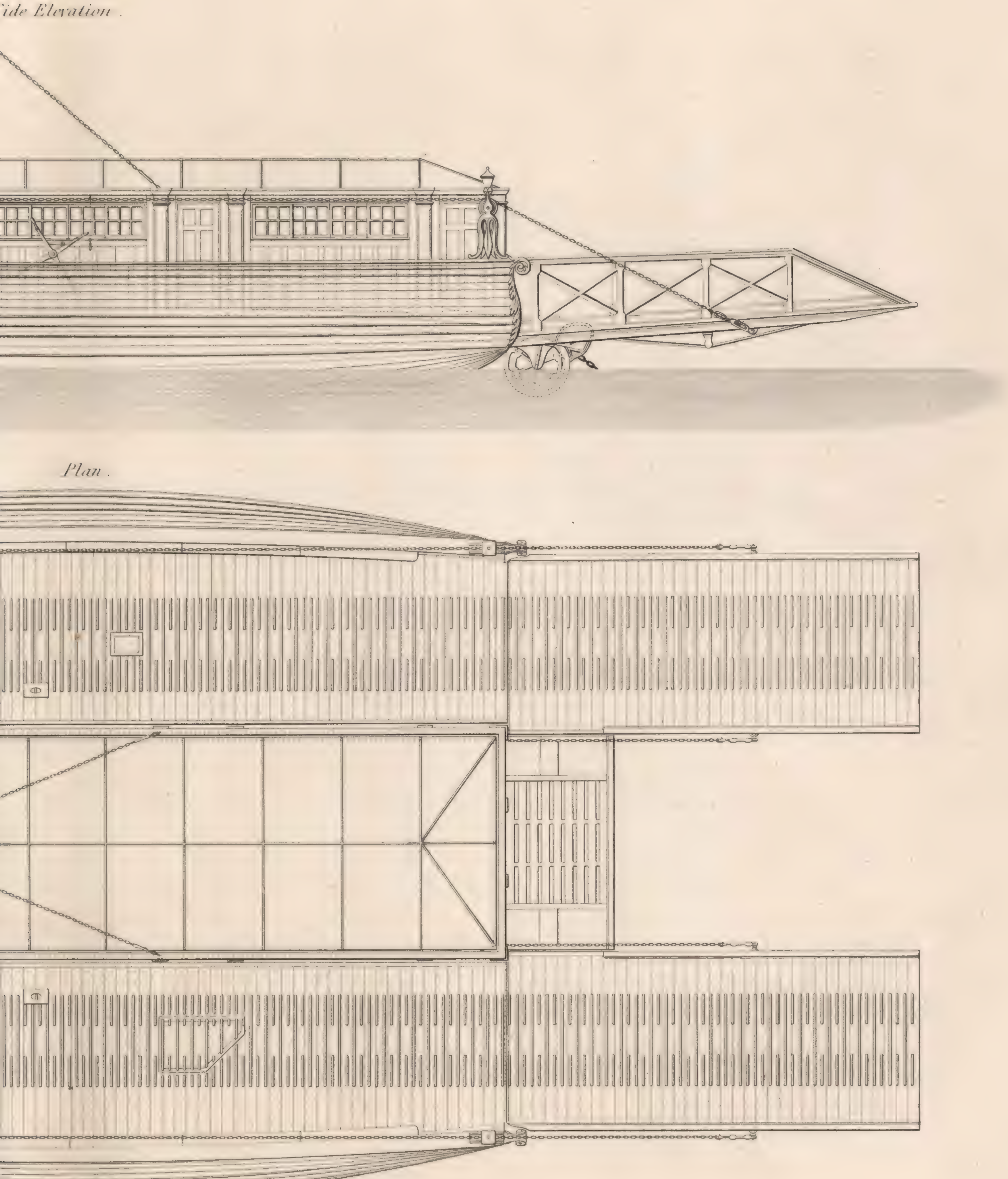
TORPOINT FLOAT



J.M. Rendel Del.

John Weale, 59, High Holborn.

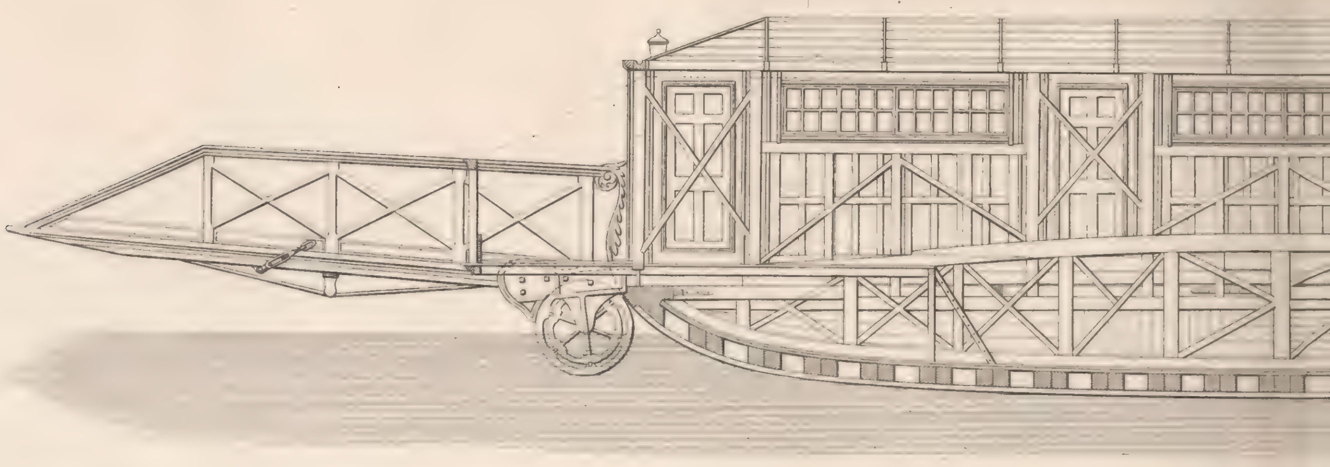
FLOATING BRIDGE.



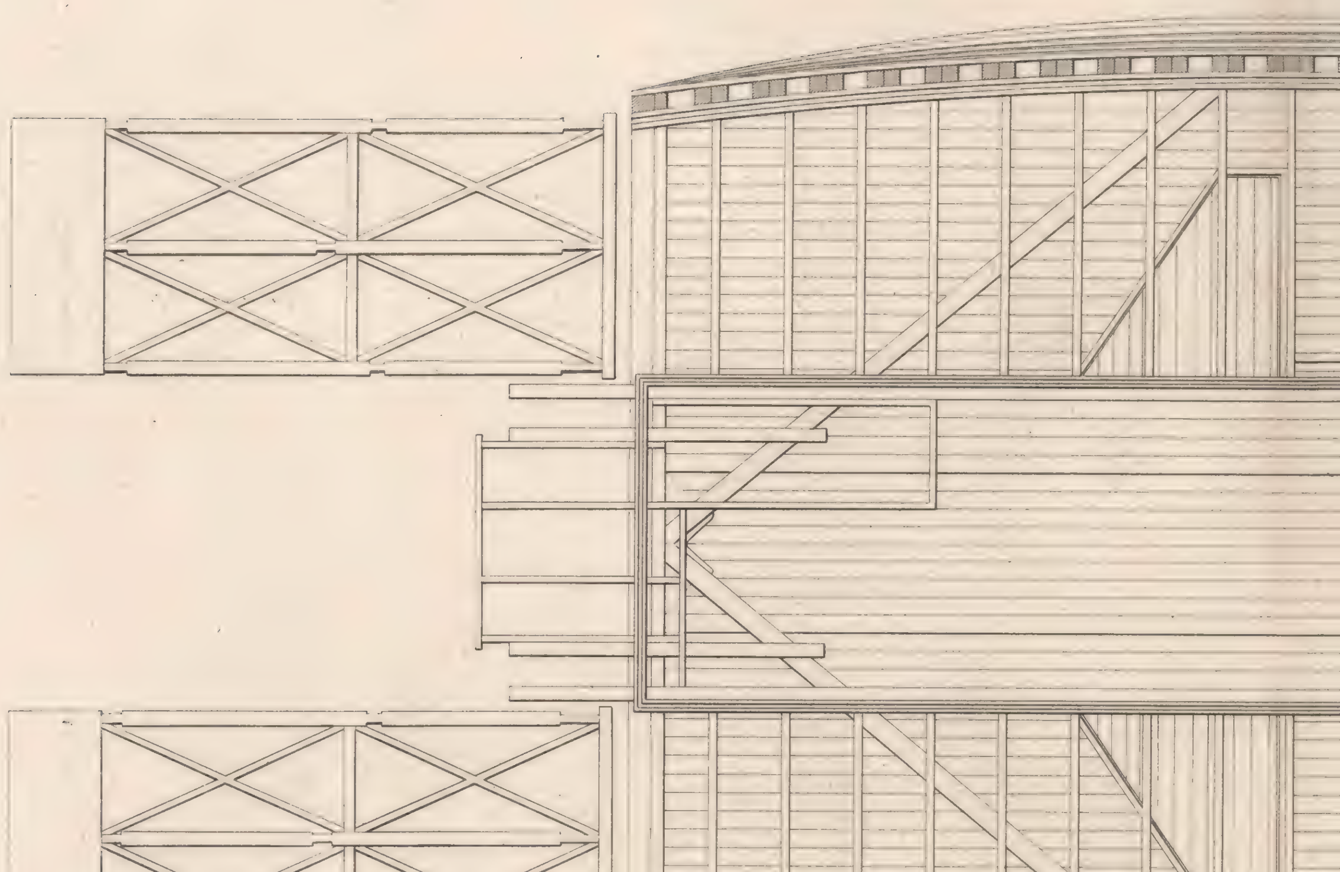
J. W. Lowry. Sculp.

TORPOINT FLOAT

Longitudinal Section thr



Plan showing the Beams & Timbers



J. M. Rendel, del.

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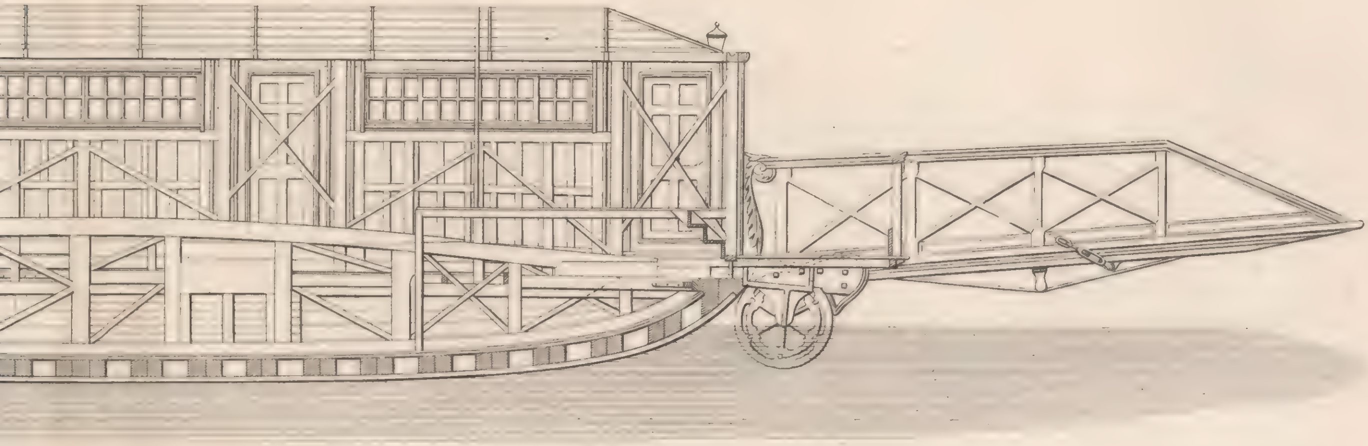
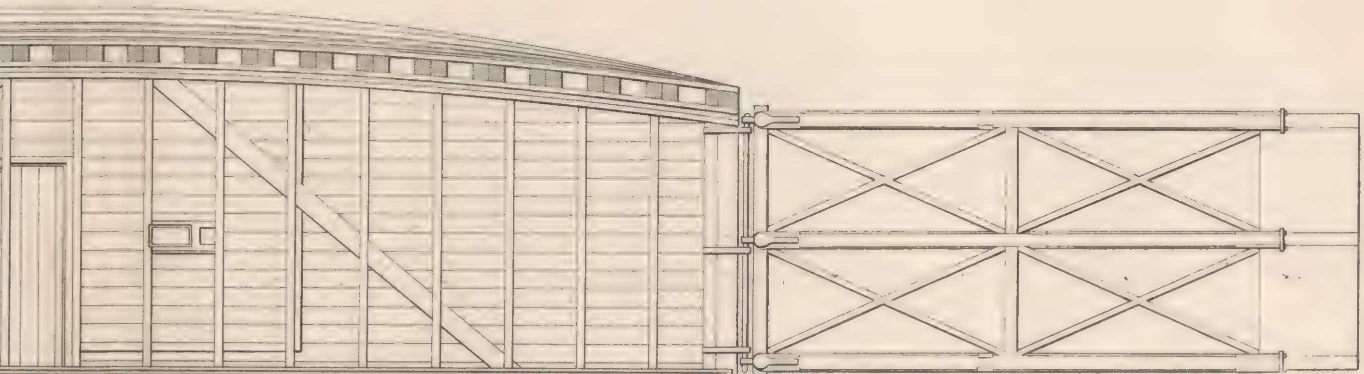
Section through the Centre.



...ms & Timbers which carry the Decks.



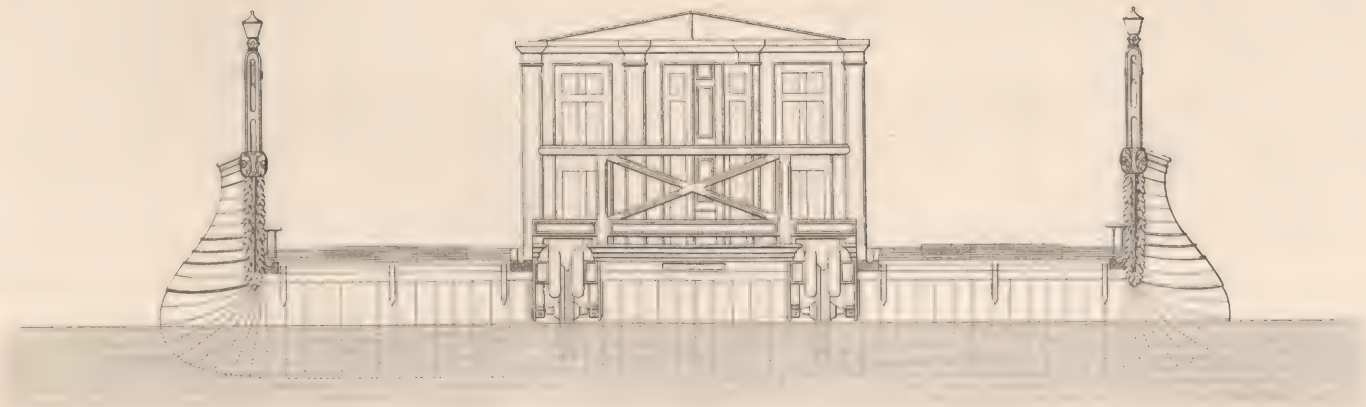
20 30 40 feet

J. W. Lowry. sc

PLATE XXII.

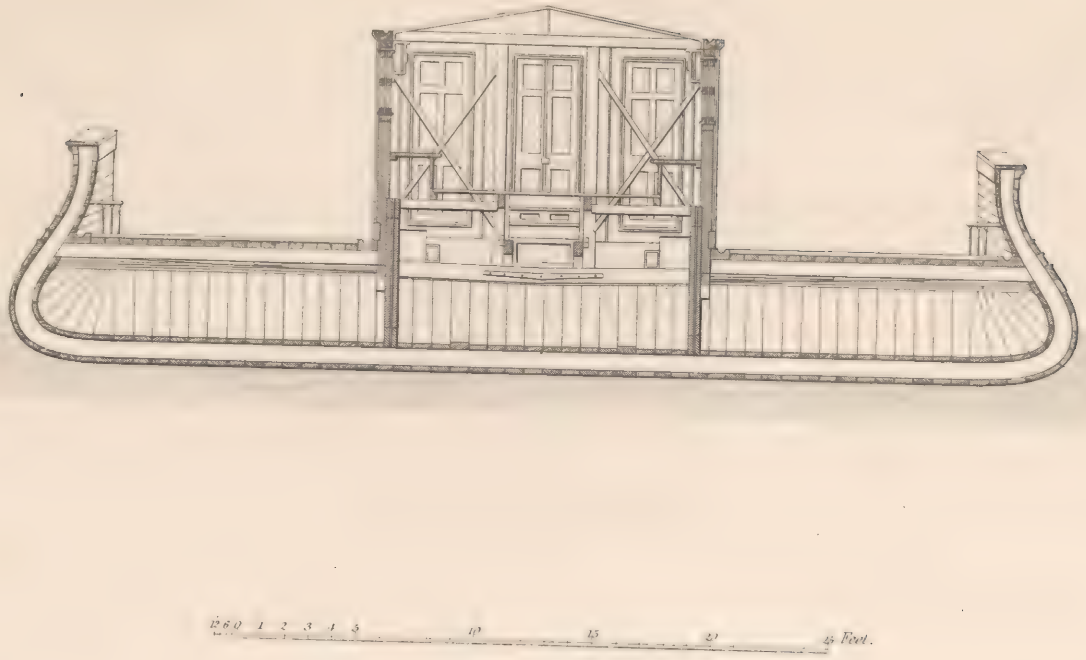
TORPOINT FLOATING BRIDGE.

End view (without the Draw Bridges.)



Transverse Section through the Centre.

Transverse Section through the Centre.



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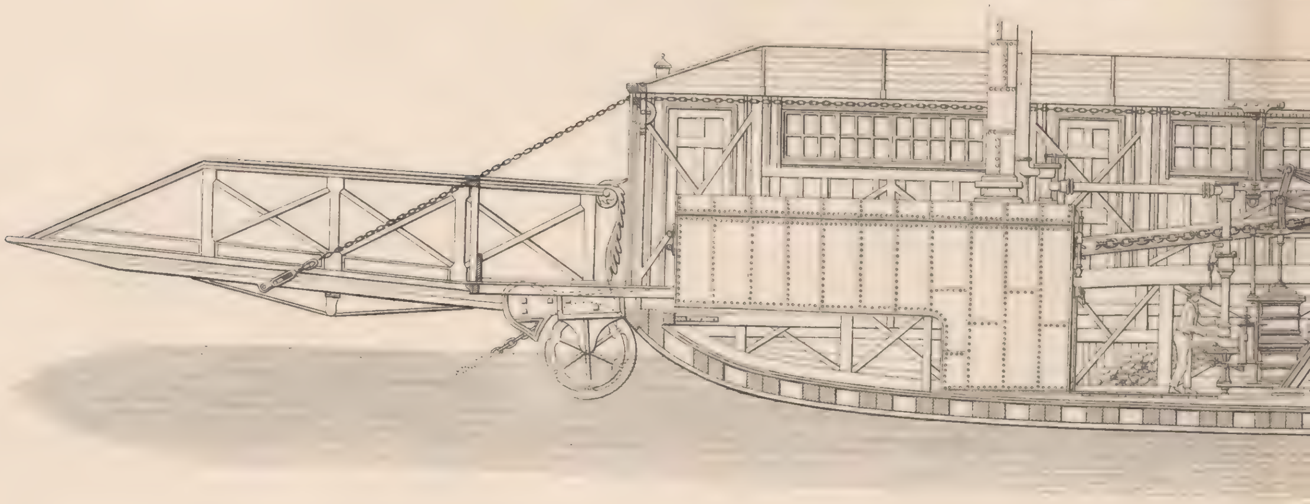
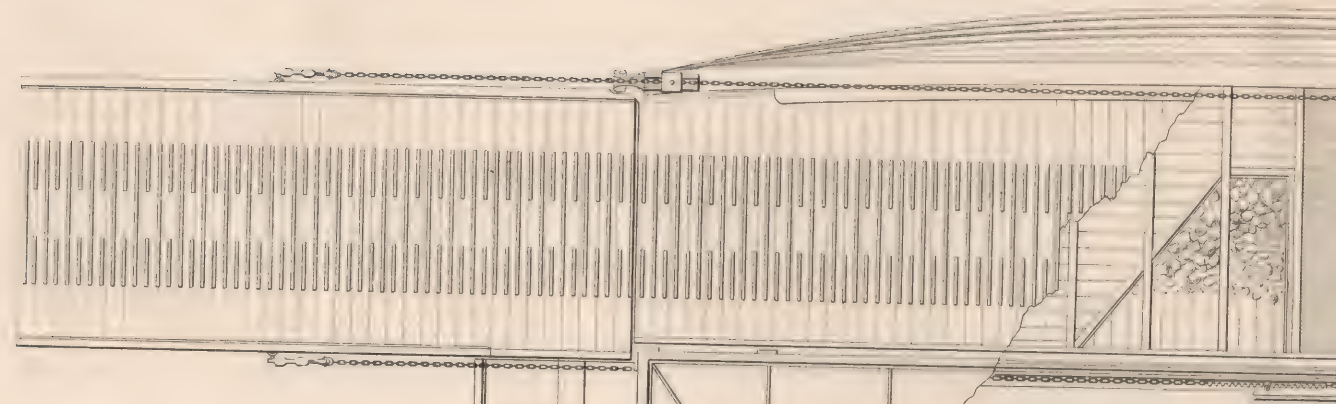
TORPOINT FLOA

Longitudinal Section sh



Plan showing the



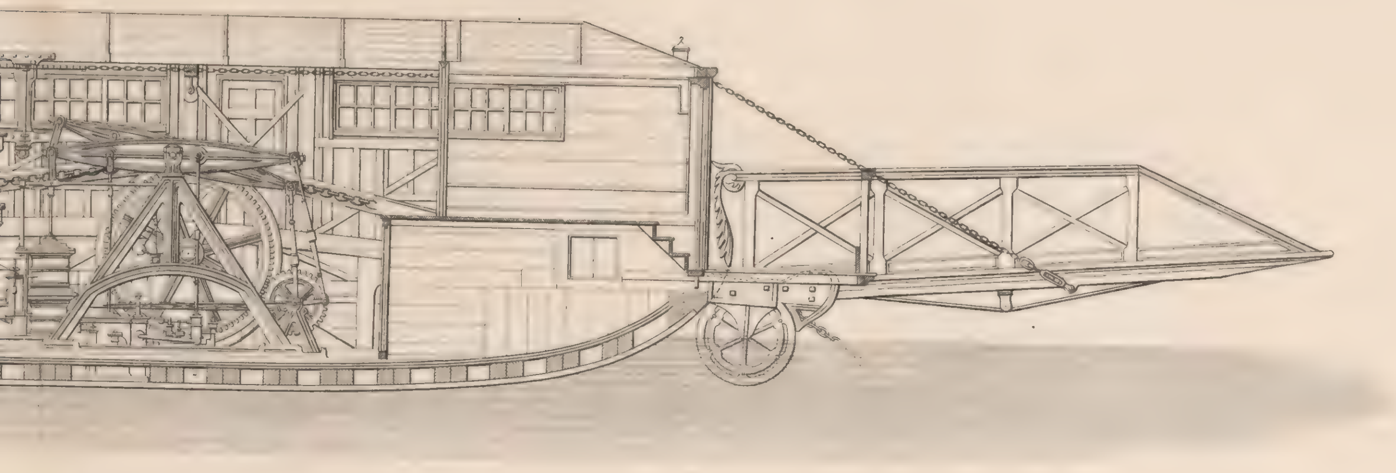
J.M. Rendel, Del.t

John Weale, 59, High Holborn

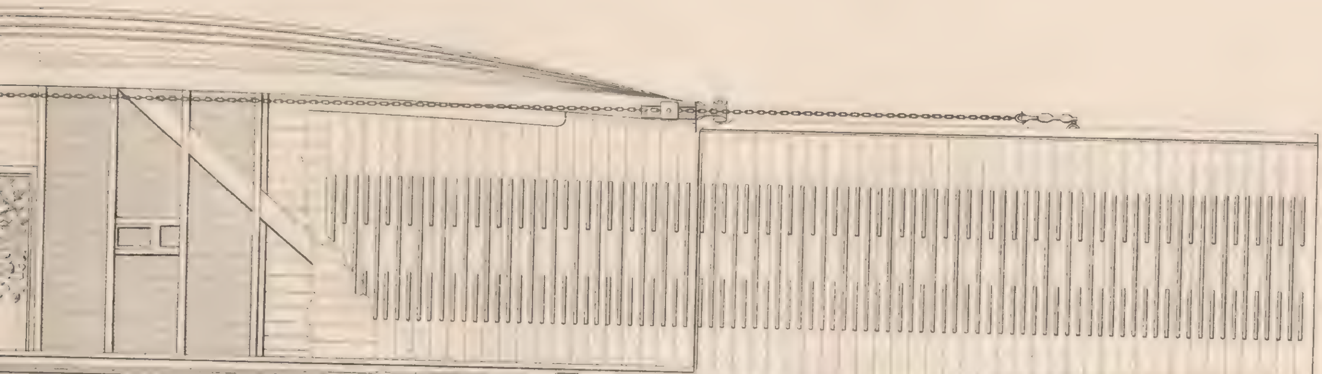
FLOATING BRIDGE.

PLATE XXIII.

...ion showing the Machinery.



...ng the Machinery.



20 30 40 feet

J. W. Lowry. Sculp.

TREDGOLD ON THE STEAM ENGINE, AND ON STEAM NAVIGATION.

LIST OF PLATES.

1 to 20. The same subjects as in the previous edition, with several corrections.

NEW PLATES.

10 B. The several Orders of Parallel Motion.
21. Mr. Kingston's Valves, as fitted on board Sea-going Steam-vessels for Blow-off, Injection, and Hand Pump Sea Valves.
22. Boilers of her Majesty's Steam Vessel of War African.
23. Boilers of her Majesty's Steam Vessel of War Medea.
24. Morgan's Paddle Wheel — Seaward's Paddle Wheel.
25. Positions of a Float of a Radiating Paddle Wheel in a Vessel in Motion—Positions of a Float of a Vertically Acting Wheel in a vessel in Motion.
26. Cycloidal Paddle Wheel fitted to the Great Western Steam Vessel, by Messrs. Maudslay, Field and Co.—Position of a Float of a Cycloidal Paddle Wheel.
27. Captain Oliver's, R.N., Five Points from Courses of Sailing a Steam Vessel.
28. Her Majesty's Steam Ship of War Phœnix sailing at Different Points in the Wind. 4 views.
29. Trial at Sailing her Majesty's Steam Ship of War Medea against the Caledonia, Vanguard, and Asia.
30. Engine of the Red Rover, Side Elevation, and Plan.
31. Longitudinal Section of ditto.
32. Cross Sections ditto, with Paddles.
33. Side Elevation of the Engine of the Pasha of Egypt's Steam Ship Nile.
34. Plan of ditto, with Paddles.
35. Cross Sections ditto, showing Boilers and Furnace.
36. Section at Paddle Wheel ditto.
37. Plan of Engine of her Majesty's Steam Ship of War Phœnix.
38. Side Elevation of ditto.
39. Cross Section of ditto, showing Paddles and Construction of Ship.
40. Engine of the Ruby Steam Vessel (Gravesend Packet), Plan and Elevation.
41. Section of one of the Engines of the Don Juan, Peninsular Company Packet.
42. Boilers of her Majesty's Ships Hermes, Spitfire, and Firefly.
43. Plan of the Engines of the Imperial Russian Steam Ships Jason and Colchis.
44. Section of ditto.
45. Longitudinal Section of ditto.
46. Section at the Shaft, Section abaft Boilers, ditto.

MARINE ENGINES FITTED WITH MR. SAMUEL HALL'S PATENT CONDENSERS.

47. Elevation of Mr. Samuel Hall's Patent Condensing Engines of the St. George Steam Packet Company's Vessel Hercules, made by Messrs. Fawcett and Preston.
48. Section of ditto.
49. Elevation of the Engine of her Majesty's Steam Ship Megæra, fitted with Messrs. Seaward's Engines and Mr. Samuel Hall's Condensers.
50. Section of ditto.
51. Messrs. Hall's, of Dartford, Engines of the William Wilberforce, Hull and London Packet, fitted with Mr. Samuel Hall's Condensers. Plan.
52. Elevation of ditto.
53. Cross Section of ditto.
54. Longitudinal Section of ditto.
55. Elevation of the Engines of the St. George Steam Packet Company's Ship Tiger, fitted with Mr. Edward Bury's Engine and Mr. Samuel Hall's Condensers. See plates 111 and 112.

WITHOUT MR. SAMUEL HALL'S PATENT CONDENSERS.

55 A. Messrs. Hall's, of Dartford, Patent Engines, fitted in the Steam Packet Dartford.
55 B. Ditto, Plan. Elevation ditto.
56 A. Cross Section ditto. Longitudinal Section ditto.
56 B. Ditto. Ditto.
57. Messrs. Fairbairn and Murray's Engine of Twenty Horse Power. Plan.
58. Ditto Section.
59. Ditto Front Elevation and Back Elevation.
60. Messrs. Fairbairn and Co.'s Ten Horse Power Engine. Elevation.
61. Plan. Sectional Plan.
62. Sectional Elevation.
63. Cross Sectional Elevation.
64. Elevation of a Locomotive Engine, manufactured by Messrs. Stephenson, of Newcastle, for the Stanhope and Tyne Railway.
65. Longitudinal Section of ditto.
66. Spring and Balance Safety Valves.
67 A. Cyclinder Cover and Connecting Rods.
67 B. Piston and Cylinder.
68. Boiler Seating of 20-horse Engine, at the manufactory of Messrs. Whitworth and Co., Manchester.
69. Messrs. Hague's Double Acting Cylinder, Slides, Sections, &c.
70 A. Side Elevation of the Engine made by Mr. Napier, of Glasgow, for the Berenice, Hon. East India Company's Armed Steamer.
70 B. Cross Section ditto.
71. Mr. Beale's Rotary Engine, Elevations.
72. Ditto, Sections.
73. Ayre's Contrivance for Preventing a Locomotive Engine from Running off a Railway.
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